②

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

LOW SIDELOBE REFLECTOR ANTENNA DESIGN
FOR COMMUNICATIONS

by

Nelson A. Armas

September, 1993

Thesis Advisor: Dr. David C. Jenn

94-06458

4 2 25 01

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE September 23, 1993	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE

LOW SIDELOBE REFLECTOR ANTENNA DESIGN FOR COMMUNICATIONS

5. FUNDING NUMBERS

6. AUTHOR(S)
Armas, Nelson

7. PERFORMING ORGANIZATION NAMES (S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the US Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The current antenna used in the Marine Radio AN/MRC-142 is a focal point fed reflector with a first sidelobe of -10 dB. A new antenna design is required with a sidelobe reduction of another 10 dB, and a minimum impact on the system upgrade cost. An improved feed consisting of a fed dipole and disk in the vicinity of a parasitic ring was designed for use with the current reflector. The disk acts as a ground plane for the dipole, with the ring narrowing the beamwidth, resulting in a stronger edge taper on the reflector.
An existing computer code based on the the method of moments was used to compute the gain and the radiation pattern. Circular parabolic reflectors of 36 inches and 48 inches were analyzed. The results show that the 36 inch reflector cannot satisfy the conditions over the entire frequency band (1350 to 1850 MHz) simultaneously. The 48 inch reflector came very close to satisfying all the conditions, although the sidelobe level is off by approximately 2 dB at wide angles in the H-plane.

14. SUBJECT TERMS

AN/MRC-142 Marine radio, Low sidelobes, Reflectors, Method of Moments

16. PRICE CODE

15. NUMBER OF PAGES
76

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18 298-102

LOW SIDELOBE REFLECTOR ANTENNA DESIGN FOR COMMUNICATIONS

by

Nelson Armas
Lieutenant, Ecuadorian Navy

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September, 1993

Author: _____
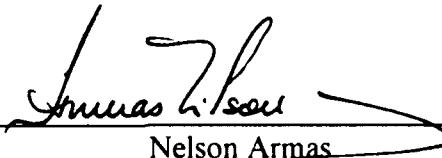
Nelson Armas

Approved By: _____
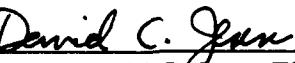
Dr. David C. Jenn, Thesis Advisor

_____
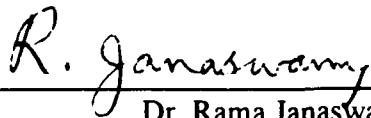
Dr. Rama Janaswamy, Second Reader

_____
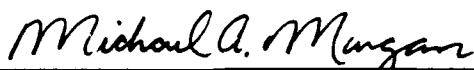
Dr. Michael A. Morgan, Chairman
Electrical and Computer Engineering Department

ii

ABSTRACT

The current antenna used in the Marine Radio AN/MRC-142 is a focal point fed reflector with a first sidelobe of -10 dB. A new antenna design is required with a sidelobe reduction of another 10 dB, and a minimum impact on the system upgrade cost. An improved feed consisting of a fed dipole and disk in the vicinity of a parasitic ring was designed for use with the current reflector. The disk acts as a ground plane for the dipole, with the ring narrowing the beamwidth, resulting in a stronger edge taper on the reflector.

An existing computer code based on the the method of moments was used to compute the gain and the radiation pattern. Circular parabolic reflectors of 36 inches and 48 inches were analyzed. The results show that the 36 inch reflector cannot satisfy the conditions over the entire frequency band (1350 to 1850 MHz) simultaneously. The 48 inch reflector came very close to satisfying all the conditions, although the sidelobe level is off by approximately 2 dB at wide angles in the H-plane.

iii

TABLE OF CONTENTS

ACKNOWLEDGMENT

Completion of this research effort would not have been possible without the help of Dr. David C. Jenn and Dr. Rama Janaswamy. Their guidance has extended beyond the scope of this work to my entire stay at the Naval Postgraduate School, and I am deeply appreciative. Additionally, I would like to acknowledge the consideration of Carmen Cibeira, whose understanding and support was a source of strength.

I. INTRODUCTION

A. BACKGROUND

An antenna is the transducer that intercepts propagating electromagnetic waves and directs them into guided waves in a transmission line. In the case of a transmitting antenna, guided electromagnetic energy in a transmission line is converted into radiated electromagnetic waves. In short, the antenna couples the system to the environment [Ref. 1].

Almost all radar, communication, and electronic warfare (EW) systems require some form of antenna. Even for highly directive antennas, all of the energy is not concentrated into the main beam; there is always radiation in directions other than the intended one. These *sidelobes*, as they are called, are of particular importance in electronic warfare, since they represent a major limitation to the system's effectiveness. Jamming signals or false targets received through a sidelobe can cause confusion and failure of a mission more easily than false signals detected by the main beam. The reduction and control of the position and magnitude of sidelobes is extremely important when attempting to localize target azimuths in a hostile electronic environment.

Antenna sidelobe control is one of the most basic methods of defeating jammers and avoiding detection. Low sidelobes also reduce multipath signals, which can cause signal fading in communications systems and tracking errors in radars. The methods of

1

sidelobe suppression for passive antennas are well known, and the technology is low risk. However, low sidelobes are accompanied by a reduction in gain, and generally require a more complicated antenna design. Consequently, there are tradeoffs in the antenna design that impact the overall system performance and cost.

B. OBJECTIVE

This thesis investigates the feasibility of reducing antenna sidelobes for the Marine Radio MRC-142. This system provides medium-range ultra high frequency (UHF) line-of-sight multi-channel radio communications over a distance of up to 35 miles. The AN/MRC-142 radio terminal set is installed in the M-998 variant of the High Mobility Multipurpose Wheeled Vehicle (HMMWV) and when deployed appears as in Figure 1.

This unit can be configured as a repeater to extend the communications range between two other systems or to overcome terrain conditions that prevent a direct line-of-sight path between the other two pieces of equipment. The AN/MRC-142 interfaces with a distant end AN/MRC-142 over a 1350 to 1850 MHz UHF radio link using parabolic antennas that are mounted on masts which can be extended up to 50 feet. The current design uses a parabolic reflector with a focal-point feed and has a first sidelobe requirement of -10 dB relative to the mainbeam. A reduction of another 10 dB is desired for the new design, with a minimum impact on the system upgrade cost.

2

50 Foot Telescoping Antenna

Rack Mounted Equipment (RME)

M-998 HMMWV
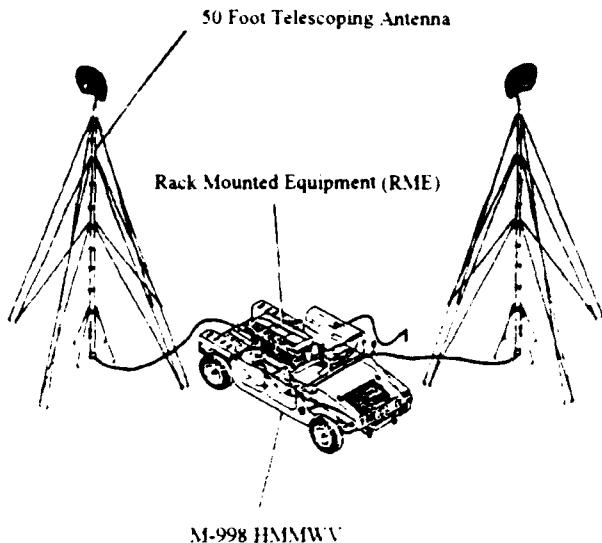
Figure 1. Deployed AN/MRC-142 Radio Terminal Set [Ref. 2].

C. METHOD OF SOLUTION

Possible options for the low sidelobe antenna include:

1. an array antenna;

2. a completely redesigned reflector and feed, or;

3. an improved feed used in conjunction with the current reflector.

The complete antenna specifications are given in the Appendix. Options 1 and 2 could satisfy the specifications in their entirety, but the cost of design and development would be significant. The third option is the one pursued here. Even though all of the antenna specifications are not achieved simultaneously with the new feed, there is significant improvement in all areas. Most importantly, the cost of the new feed is minimal because of its simplicity.

3

The proposed feed design consists of a fed dipole in the vicinity of a parasitic ring and disk as shown in Figure 2 [Ref 3] Essentially the disk acts as a ground plane for the dipole and the ring narrows the beamwidth, resulting in a stronger edge taper on the reflector The dimensions are chosen to minimize the sidelobes This "tuning" approach is narrow band and, as discussed in Chapter III, does not allow an optimum feed design for both the transmit and receive frequencies
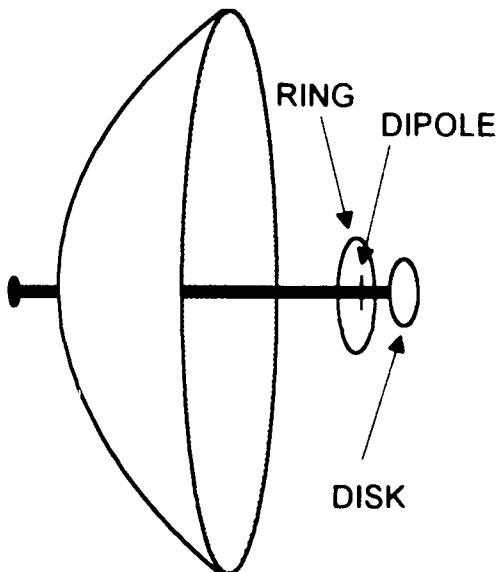
Figure 2. Dipole-Disk Antenna with Ring Used as a Feed in Paraboidal Reflector.

D.   SCOPE OF THESIS

In Chapter II the method of analysis is discussed in detail. All of the gain and pattern data presented are generated using the method of moments. Chapter III discusses

the tradeoffs involved in the antenna design. As mentioned earlier, the greatest challenge was selecting the geometrical parameters to provide acceptable performance at both frequencies (1350 MHz and 1850 MHz). Finally, Chapter IV presents a summary of the work performed along with some conclusions.

II. THEORETICAL BACKGROUND

A. E-FIELD INTEGRAL EQUATION AND THE METHOD OF MOMENTS

To determine the pattern and gain of a reflector antenna, it is first necessary to find the current on the reflector surfaces. This is accomplished by solving an integral or differential equation for the current which is derived from Maxwell's equations and the boundary conditions. For wire and surface geometries of arbitrary complexity, the integral or differential equation must be solved numerically on a high speed digital computer. The method of moments (MM) is such a technique which reduces the E-field integral equation (EFIE) to a matrix equation which is then solved on a computer [Ref. 4]. The following paragraphs summarize the method of moments technique. Phaser notation is used throughout and $e^{j\omega t}$ time convention is assumed and suppressed.

If the current on a body is known, then the scattered (or radiated) field can be determined from [Ref. 5]

$$\bar{E} = -\nabla\phi - j\omega\bar{A} = -j\omega\bar{A} - j\frac{1}{\omega\mu\epsilon}\nabla(\nabla \bullet \bar{A}), \tag{1}$$

where $\omega = 2\pi f$ is the radian frequency, and μ and ϵ are the permeability and permittivity of free space. $\bar{A}$ is the magnetic vector potential, which can be represented as

$$\bar{A} = \frac{\mu}{4\pi}\iint_s \bar{J}_s(x',y',z')\frac{e^{-jkR}}{R}ds' \tag{2}$$

where $\bar{J}_s$ is the surface current and S refers to the surface of the conductor.

The electric field integral equation is based on the boundary condition that the total

tangential electric field on a perfectly electric conducting (PEC) surface of an antenna or

scatterer is zero. This can be expressed as

$$\bar{E}_t^i(\bar{r}=\bar{r}_s)=\bar{E}_t^i(\bar{r}=\bar{r}_s)+\bar{E}_t^s(\bar{r}=\bar{r}_s)=0 \quad \text{on } S \tag{3}$$

where S is the conducting surface of the antenna or scatterer, as stated before, and $\bar{r}=\bar{r}_s$
is the distance from the origin to any point on the surface of the antenna or scatterer. The

subscript "t" indicates tangential components.

Referring to Figure 3, Equations (1) and (2) can be combined and expressed as
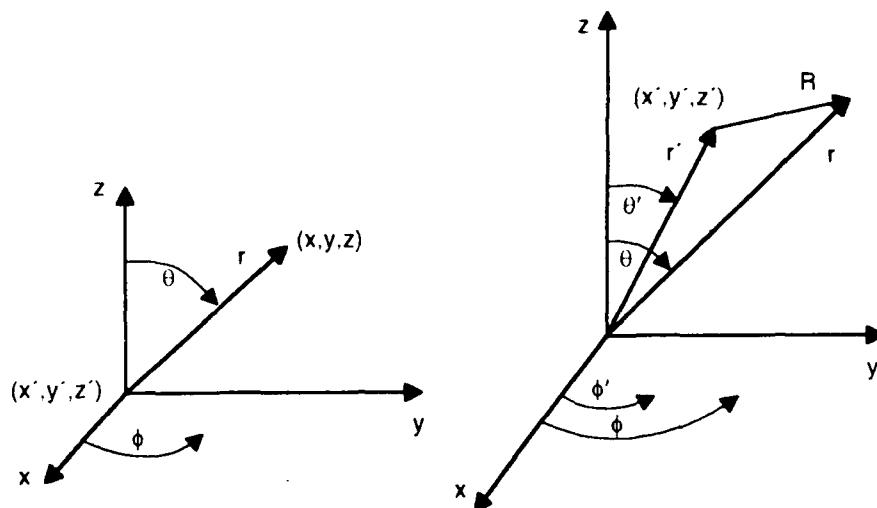
Figure 3. Coordinate Systems for Computing Radiation Fields.

7

$$\bar{E}^s(\bar{r}) = -j\frac{\eta}{\beta}[\beta^2\iint_s \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds' + \nabla\iint_s \nabla' \cdot \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds'], \qquad (4)$$

where

$$G(\bar{r},\bar{r}') = \frac{e^{-jkR}}{4\pi R}, \qquad (5)$$

and

$$\bar{R} = |\bar{r} - \bar{r}'|. \qquad (6)$$

Now, applying the boundary condition of Equation (3) gives

$$\bar{E}^s(\bar{r}) = E_i^s(\bar{r}_s) = \frac{j\eta}{\beta}[\beta^2\iint_s \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds' + \nabla\iint_s \nabla' \cdot \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds']. \qquad (7)$$

This is an integral equation with $\bar{J}_s$ as the unknown. Equation (7) is referred to as the electric-field integral equation. In Equation (7), ∇ and ∇' are the gradients with respect to the observation (unprimed) and source (primed) coordinates, respectively, and

$$G(\bar{r},\bar{r}')$$

is the Green's function for a three dimensional radiator or scatterer.

For convenience, an operator L can be defined which will operate on $\bar{J}_s$

$$L(\bar{J}_s) = j\omega\mu\iint_s \bar{J}_s G; \ ds' + \frac{j\epsilon}{\omega}\nabla[\nabla\iint_s \bar{J}_s G; \ ds' + \iint_s \bar{J}_s \cdot \nabla G; \ ds' \qquad (8)$$

where unknown current $\bar{J}_s$ depends only on the primed quantities. G is a scalar quantity that depends on both the primed and unprimed quantities. It is desirable to have all the differential operations in terms of the primed variables of integration. Equation (8) can therefore be written as

$$L(\bar{J}_s) = j\omega\mu\iint_s \bar{J}_s G; \ ds' + \frac{j\epsilon}{\omega}\nabla[\iint_s G; \ \nabla \cdot \bar{J}_s ds' + \iint_s \bar{J}_s \cdot \nabla; \ G; \ ds', \qquad (9)$$

where the vector identity

$$\nabla(\bar{J}_s \bullet \nabla G) = (\bar{J}_s \bullet \nabla)\nabla G + (\nabla G \bullet \nabla)\bar{J}_s + \bar{J}_s \times (\nabla \times \nabla G) + \nabla G \times (\nabla \times \bar{J}_s). \quad (10)$$

has been used.

The gradient of G in terms of the two sets of coordinates is related by

$$\nabla G = -(jk + \tfrac{1}{r})\frac{e^{-jkr}}{4\pi r}\hat{r} = -\nabla'G. \quad (11)$$

Using the surface divergence theorem developed by Mautz and Harrington [Ref. 5], it can be shown that

$$\iint_s \nabla' \bullet (\bar{J}_sG)ds' = 0. \quad (12)$$

Finally, Equation (7) can be written as

$$L(\bar{J}_s) = \iint_s [j\omega\eta\bar{J}_sG - \tfrac{j\varepsilon}{\omega}\nabla[(\nabla' \bullet \bar{J}_s)G]]ds'. \quad (13)$$

Now the electric field integral equation can be represented as

$$\bar{E}_t^i(r_s) = L(\bar{J}_s). \quad (14)$$

Equation (14) can be solved numerically using the method of moments. The current on the antennas is expanded in terms of a finite series of known basis functions with unknown amplitudes. The antenna under consideration consists of surfaces and thin wires, so basis functions must be defined on each. On a surface two orthogonal components are required. The coordinate system for the reflector is shown in Figure 4 and the following basis functions defined on the surface [Ref. 6]:

9

SEGMENTED REFLECTOR GENERATING CURVE

x

ρ_{i+1}

ρ_i

v_i

D/2

t=0

z_{i+1} z_i

z

AXIS OF SYMMETRY

t
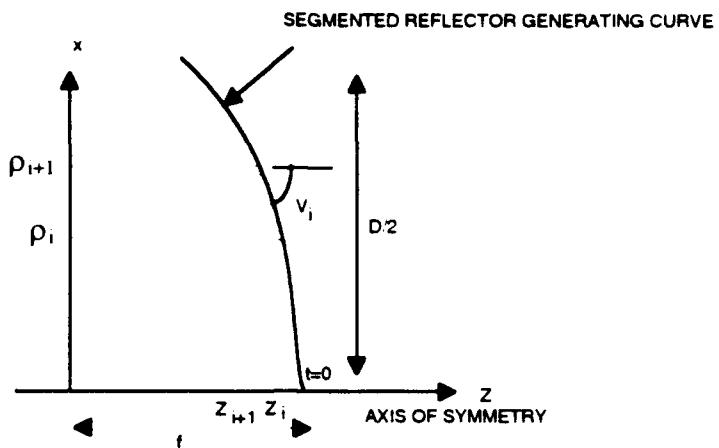
Figure 4. A Reflector Geometry for Method of Moments.

$$\bar{J}^t_{ni} = \hat{t}\frac{T_i(t)}{\rho}e^{-jn\phi}, \qquad n = 0, \pm1, \ldots \pm\infty, \quad i = 1, 2, \ldots, N_s - 2$$
$$\bar{J}^\phi_{ni} = \hat{\phi}\frac{P_i(t)}{\rho}e^{-jn\phi}, \qquad n = 0, \pm1, \ldots \pm\infty, \quad i = 1, 2, \ldots, N_s - 1 \tag{15}$$

$T_i(t)$ is the triangle function (which extends over two segments, i and $i + 1$) and $P_i(t)$ is the pulse function. A point on the surface of the antenna is specified by the coordinates (t, ϕ), where t is an arclength variable along the reflector generating curve. The distance of a point from the axis of symmetry (z-axis) is given by ρ and N_s is the number of surface generating points. A discussion leading to the choice of these basis functions is given by Mautz and Harrington [Ref. 5].

For thin wires the radius "a" is much less than a wavelength and the current will only have an axial component. Thus the operator ∇ becomes $\hat{t}(\partial/\partial t)$, where t is the arc length along the wire. Furthermore, the current is constant around the wire and $\iint_s ds'$

10

reduces to $2\pi a \int_L dt'$, as shown in Figure 5. Thus appropriate basis functions on the wire are [Ref 7]:
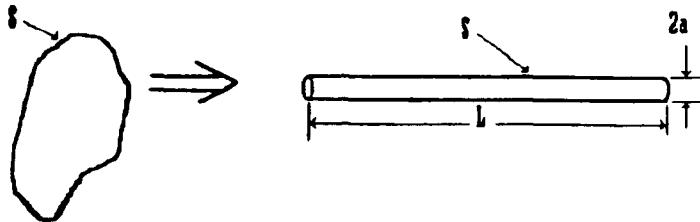
Figure 5. Thin Wire Approximation.

$$\bar{J}_i = \hat{t}\frac{T_i(t)}{2\pi a}, \qquad i=1,2...,N_w. \qquad (16)$$

In this case $\hat{t}$ is a unit vector along the wire axis and N_w is the number of wire generating points. The total current is the sum over all expansion functions

$$\bar{J}_s = \sum_{m=1}^{N_w-2} I_m^w \bar{J}_m^w + \sum_{n=-\infty}^{\infty}\left[\sum_{p=1}^{N_s-2} I_{pn}^t \bar{J}_{pn}^t + \sum_{q=1}^{N_s-1} I_{qn}^\phi \bar{J}_{qn}^\phi\right]. \qquad (17)$$

The coefficients I are the unknowns which need to be determined.

From the linearity of L, Equation (14) can be combined with Equation (17) as follows

$$\bar{E}_t^i = \sum_{i=1}^{N_b} I_i L(\bar{J}_i). \qquad (18)$$

11

where N_b is the total number of basis functions of both types. N_b equations need to be provided to enable a solution for the unknown constants I_i. Galerkin's method is used to reduce Equation (18) to a matrix equation, and weighting functions are defined such that $\bar{W}_k = \bar{J}_k^*$ (Ref. 8, 9]. Each side is multiplied by each of the basis functions and then each side integrated. The result is N_b equations of the form

$$\iint_{s_{k_i}} \bar{E}^i \bullet \bar{W}_k \, ds = [\iint_{s_{k_1}} \bar{W}_k \bullet I_1 L(\bar{J}_1) + \iint_{s_{k_2}} \bar{W}_k \bullet I_2 L(\bar{J}_2) + \ldots + \iint_{s_{k_N}} \bar{W}_k \bullet I_N L(\bar{J}_N)] ds$$
$$k = 1, 2, \ldots N_b \tag{19}$$

which can be written as

$$\iint_{s_k} \bar{E}^i \bullet \bar{W}_k \, ds = \iint_{s_{k_i}} [\bar{W}_k \bullet \sum_{i=1}^{N_b} I_i L(\bar{J}_i) ds] \tag{20}$$

Interchanging summation and integration,

$$\iint_{s_k} \bar{E}^i \bullet \bar{W}_k \, ds = \sum_{i=1}^{N_b} I_i \iint \bar{W}_k \bullet L(\bar{J}_i) ds \tag{21}$$

Equation (21) can be cast in the form

$$V_k = \sum_{i=1}^{N_b} Z_{ik} I_i \tag{22}$$

for $k = 1, 2, \ldots, N_b$, where the impedance elements are given by

$$Z_{ik} = \iint_s ds \iint_s \left[j\omega\mu \bar{W}_k \bullet \bar{J}_i - \frac{j}{\omega\varepsilon}(\nabla' \bullet \bar{J}_i)(\nabla \bullet \bar{W}_k) \right] G ds' \tag{23}$$

The excitation elements are defined by

$$V_k = \iint_s \bar{W}_k \bullet \bar{E}^i ds, \tag{24}$$

12

In matrix notation Equation (22) becomes

$$[V] = [Z][I], \tag{25}$$

and the unknown coefficients are determined by solving the matrix equation

$$[I] = [Z]^{-1}[V]. \tag{26}$$

Submatrices in Equation (25) associated with the $\hat{t}$ and $\hat{\phi}$ surface components can be identified as follows

$$\begin{bmatrix} [V_n^t] \\ [V_n^\phi] \end{bmatrix} = \begin{bmatrix} [Z_n^{tt}][Z_n^{t\phi}] \\ [Z_n^{\phi t}][Z_n^{\phi\phi}] \end{bmatrix} \begin{bmatrix} I_n^t \\ I_n^\phi \end{bmatrix}. \tag{27}$$

The impedance matrix will have the following block structure when all of the surface and wire basis functions are considered

$$\begin{bmatrix} Z_{-M}^{ss} & \cdots & \cdots & \cdots & \cdots & \cdots & Z_{-M}^{sw} \\ & \ddots & & & & & \vdots \\ & & & & & & \vdots \\ \vdots & & Z_0^{ss} & & Z_0^{sw} & & \vdots \\ & & & \ddots & \vdots & & \\ & & & & \ddots & Z_M^{sw} \\ Z_{-M}^{ws} & \cdots & \cdots & Z_0^{ws} & \cdots & Z_M^{ws} & Z_M^{ww} & Z_{-M}^{ww} \end{bmatrix} \begin{bmatrix} I_{-M}^s \\ \vdots \\ \vdots \\ I_0^s \\ \vdots \\ I_M^s \\ I^w \end{bmatrix} = \begin{bmatrix} V_{-M}^s \\ \vdots \\ \vdots \\ V_0^s \\ \vdots \\ V_M^s \\ V^w \end{bmatrix}. \tag{28}$$

The superscripts s and w refer to surface and wire, respectively. Although n in Equation (17) can take on values between $\pm \infty$, it has been truncated at $\pm M$ in the above matrix. In practice, when the feed is on the reflector axis of symmetry, a converged solution can be obtained with $M = 1$. If the pattern is calculated for the antenna

13

transmitting, the excitation vector will have only one non-zero value corresponding to the dipole feed point.

The unknown expansion coefficients are determined by solving the matrix in Equation (27) for [I]. To compute the electric field, the coefficients are used in Equation (17), which in turn is used in Equations (1) and (2). Define a measurement vector,

$$R_m = \iint_s \overline{E}_r \cdot \overline{J}_s ds, \qquad (29)$$

where $\overline{E}_r$ denotes a unit radiated plane wave weighted by the current on S. In general $\overline{J}_s$ will give rise to both θ and ϕ components in the far field. The radiated θ component is of the form

$$\overline{E}_r = \hat{\theta} e^{-jk \cdot r} = \hat{\theta} e^{-jk[xu+yv+zw]}, \qquad (30)$$

where $u = \sin\theta\cos\phi$, $v = \sin\theta\sin\phi$, and $w = \cos\theta$. By substituting Equation (30) into Equation (29), there results

$$R_m^\theta = \iint_s e^{-jk[xu+yv+zw]}(\hat{\theta} \cdot \overline{J}_s)ds. \qquad (31)$$

The total θ component of the electric field is the superposition of all surface current contributions

$$E_\theta = \frac{-jk\eta}{4\pi r}e^{-jkr}\sum_m R_m^\theta I_m. \qquad (32)$$

The analysis holds true for the ϕ component. The measurement elements are

$$R_m^\phi = \iint_s e^{-jk[xu+yv+zw]}(\hat{\phi} \cdot \overline{J}_s)ds, \qquad (33)$$

14

and the electric field is then defined by

$$E_\phi = \frac{-jk\eta}{4\pi r}e^{-jkr}\sum_m R_m^\phi I_m .$$ (34)

B. GAIN CALCULATION

The degree to which any particular antenna pattern is concentrated into a beam is known as *directivity* which is defined by

$$D = \frac{P_{max}}{P_{ave}} ,$$ (35)

where P_{max} is the maximum power flux radiated, and P_{ave} is the average power flux radiated. Since the average power flux radiated is equal to the total power radiated (P_{tot}) divided by 4π steradians,

$$D = 4\pi \frac{P_{max}}{P_{tot}} .$$ (36)

Directivity, as defined above, is a function of the antenna pattern only, and does not take into account the antenna efficiency or losses. In order to compare the relative performance of antennas in any electronic-warfare system, it is necessary to consider antenna efficiency. The pertinent quantity is gain G which is defined as

$$G = KD ,$$ (37)

where K is the efficiency factor ($0 \leq K \leq 1$). Thus it is seen that for a 100% efficient antenna (K = 1), the gain would be equal to the directivity. For all practical antennas K < 1. Gain is frequently expressed as a decibel ratio

$$G, db = 10 \log_{10} G. \tag{38}$$

A very important relationship exists between gain, physical antenna dimensions, and electrical wavelength, expressed by

$$G = 4\pi \frac{KA}{\lambda^2}, \tag{39}$$

where A is the "effective" area of the antenna and λ is the wavelength. The effective area of the antenna and the wavelength must be expressed in the same units (meters, inches, feet, etc.). The total radiated power required in Equation (36) can be obtained by integrating the electric field over a sphere

$$P_{tot} = \int_0^{2\pi} \int_0^{\pi} \{ |E_\theta|^2 + |E_\phi|^2 \} r^2 \sin\theta d\theta d\phi \tag{40}$$

where E_θ and E_ϕ are known from Equations (32) and (34).

16

III. LOW SIDELOBE ANTENNA DESIGN STUDY

A. SUMMARY OF TRADEOFFS IN THE ANTENNA DESIGN

The purpose of this thesis is to achieve a reduction in the antenna sidelobes for the Marine radio AN/MRC-142. The approach will be to upgrade the existing reflector in Figure 6 by implementing a feed design similar to that of Kildal and Skyttemyr [Ref. 3] shown in Figure 2 of Chapter I.
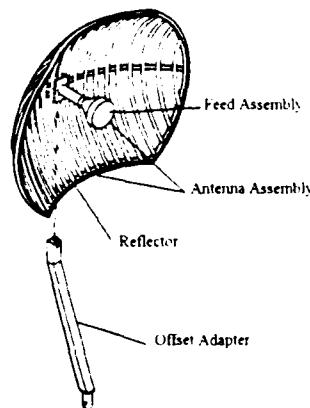
Figure 6. AN/MRC-142 Antenna Assembly and Offset Adapter [Ref. 2.].

The size of the reflector aperture is 36 x 48 inches as shown in Figure 7. The projected aperture is not circular, but has two circular segments removed. The method of moments code that was used to compute the gain and radiation pattern can only handle rotationally symmetric reflectors. In the design of the antenna, circular parabolic

17

reflectors of 36 and 48 inches were analyzed Additionally, the structure supports only vertical currents, whereas the method of moments code assumes radial and azimuthal currents (solid surface) The actual AN/MRC-142 performance will lie somewhere between the two The pattern will resemble the 48 inch reflector in the plane of the wide dimension, and the 36 inch reflector in the plane of the narrow dimension The effect on gain can be accurately estimated based on the area reduction from the 48 inch diameter circular antenna due to removal of the circular segments
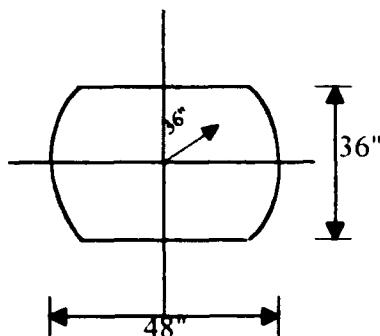
Figure 7. Antenna Radius Determination.

The reflector surface is a section of a parabaloid and is fed from the front Four factors affect the efficiency of this type of antenna:

1. Spillover efficiency;

2. Illumination efficiency;

3. Blockage by the feed;

18

4   Cable and line losses from the antenna input to the feed

Taking into consideration all these factors, most of the burden in maximizing the efficiency is placed upon the antenna feed The dipole-disk antenna, which essentially consists of a halfwave dipole over a circular plane reflector, is widely used as feed for paraboloidal reflector antennas at VHF and UHF A method of improving this feed consists in incorporating a circular conducting beam-forming ring (BFR) over the dipole in a plane parallel to the disk The beam-forming ring compresses the H-plane pattern of the dipole-disk feed, whereas it has no significant effect on the E-plane pattern When this antenna is used as feed for paraboloidal reflectors, it exhibits near-identical principal plane aperture illumination and reduces H-plane spillover lobes

The diameter of the disk should be as small as possible in order to reduce blockage loss However a small disk and ring result is a broad feed radiation pattern which does not provide sufficient edge taper for a low sidelobe pattern To obtain the best performance a parametric study was performed for the geometrical quantities shown in Figure 8 and listed in Table 1 The parameters and their effect in antenna radiation pattern and gain discussed in the following sections All dimensions used by the computer code are in wavelengths

1. Reflector Size

The size of the reflector is 36 x 48 inches as shown in Figure 7 Two different designs were obtained for each frequency: one for 36 inches and the other one for 48 inches At 1350 MHz, the wavelength is 8.75 inches and at 1850 MHz the wavelegth is

6.38 inches. Thus 36 inches corresponds to 4.1λ and 5.6λ, while 48 inches corresponds to 5.5λ and 7.5λ at these two frequencies.

The focal-length-to-diameter ratio (f/D) of the existing reflector antenna could not be determined from AN/MRC-142 technical manuals. Typical values are in the range of 0.3 to 0.55. Smaller values are preferable to reduce spillover loss and increase edge taper. A value of 0.4 was chosen for f/D. This parameter could be varied slightly without significant modification of the antenna's gain and pattern.
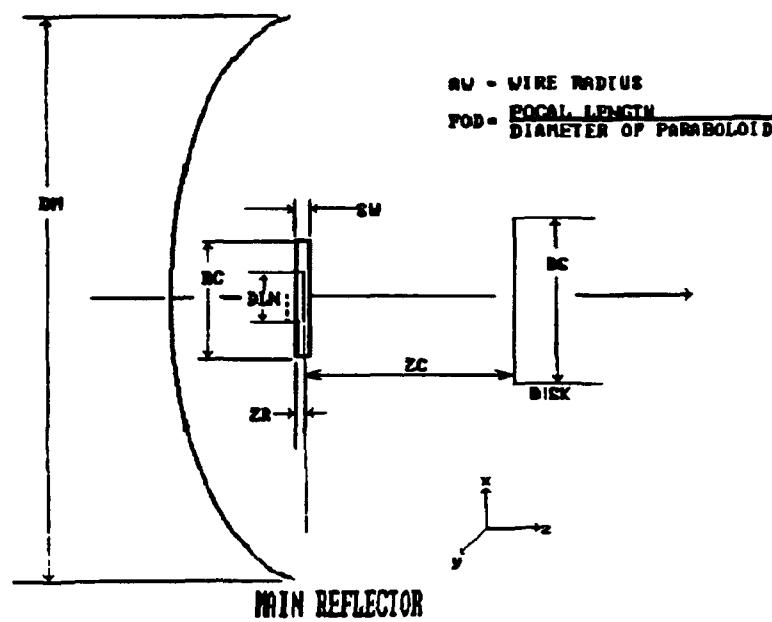
Figure 8. Program Parameters

TABLE 1. DESIGN PARAMETERS	
DM =	diameter of paraboloid
DS =	diameter of disk
ZC =	distance of dipole to ground plane
FOD =	focal length to diameter ratio of the parabolid
ZR =	distance of ring from fed dipole along the z axis
RC =	radius of ring
SW =	ring width (modeled as a thin strip)
DLN =	fed dipole length
PLN =	parasitic director dipole length
DDIP =	distance between DLN and PLN along the z axis
AW =	radius of dipoles
HLGTH =	parasitic (H plane) dipole length (not used)
DHP =	H plane dipole distance from feed along the y axis (not used)

2. Gain Calculation

Gain estimates for the reflector and feed were obtained by first integrating the total electric field to find the total radiated power P_{tot}. The result is then used in Equation [36] to determine the directivities shown in Table 2. These numbers include spillover and aperture efficiency because the total field is integrated (that is, feed plus scattered fields).

Losses that are not accounted for and thus determine the value of K in Equation [37] include:

1. Transmission line losses for the cable that feeds the dipole. Assuming 0.5 dB/ft and 3 ft of cable yields 1.5 dB of loss.

2. Reflection loss from the reflector surface. This is due to the fact that the surface is a grid rather than a solid. A conservative estimate is 0.5 dB.

3. Any impedence mismatch loss. A VSWR of 2:1 results is approximately 0.5 dB of loss.

Based on the above numbers the total loss is about 2.5 dB. The corresponding gains are shown in Table 3.

TABLE 2. CALCULATED DIRECTIVITIES.		
	48 inches	36 inches
1350 MHz	24.75 dB	22.19 dB
1850 MHz	27.44 dB	24.90 dB

TABLE 3. CALCULATED GAINS WITH LOSS.		
	48 inches	36 inches
1350 MHz	22.25 dB	19.19 dB
1850 MHz	23.94 dB	21.90 dB

B.   MODIFICATIONS TO ANTENNA DESIGN

Each of the parameters of the feed and reflector were varied in small increments and their effect on the antenna pattern and gain was evaluated. The results are summarized below.

1. Baseline Feed Design

The dimensions of the baseline feed design are listed in Table 4. The disk serves as a ground plane for the dipole. The phase center of the feed will vary with frequency and angle. If the disk is an effective ground plane the phase center of the dipole and its image will be approximately at the midpoint of the two. However in the following discussion the dipole is considered to be the center of the feed.

Low sidelobes require a strong amplitude taper across the reflector, which in turn requires a narrow feed beamwidth. Generally a narrow feed beamwidth is associated with a feed aperture which results in increased blockage. Thus there is a tradeoff between sidelobe taper and blockage loss.

The geometrical parameters in Table 4 were the starting point for the parametric study, which is summarized in the following sections. The baseline antenna performance is shown in Figure 10. The solid line is the E-plane ($\phi=0°$) pattern and the dashed line the H-plane ($\phi=90°$) pattern.
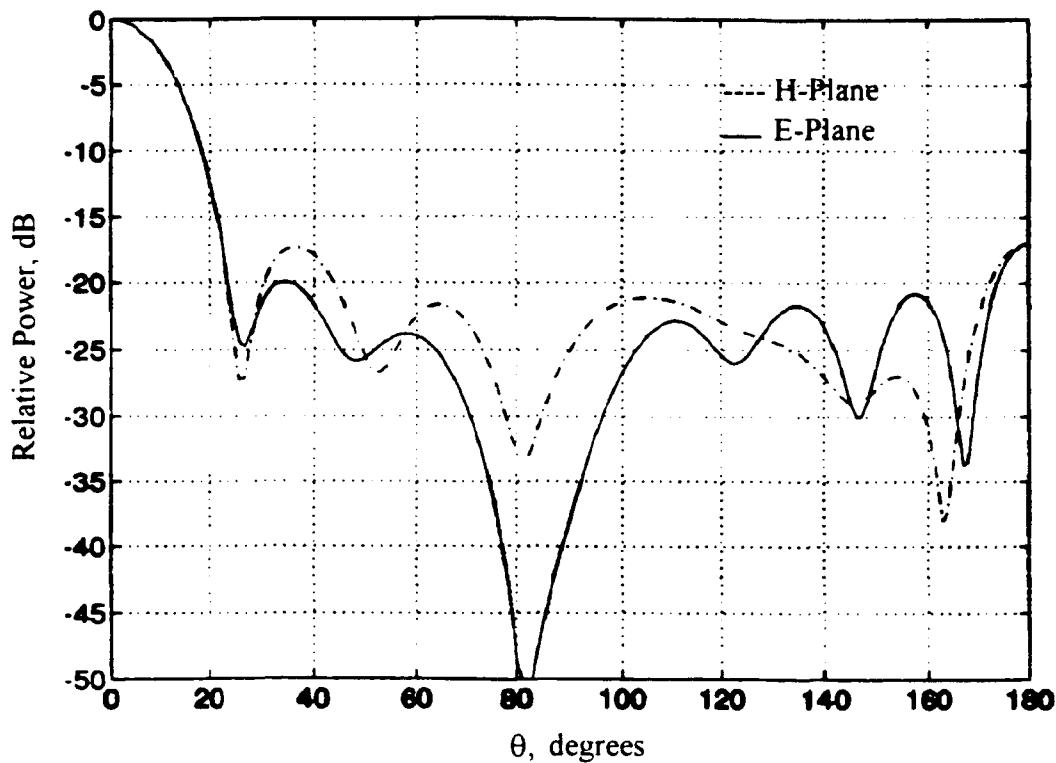
Figure 10. Baseline Antenna Pattern.

TABLE 4. BASELINE FEED GEOMETRY		
Variable	Value	Z distance or coordinate[1]
disk diameter	4.1	Zc = .25
ring diameter	0.7	Zr = 0.0
fed dipole length	0.5	Zd = -0.25
parasitic dipole length	not part of baseline design	
fed dipole height above disk	0.5	Zc-Zd
ring heigth above disk	0.25	Zc-Zr
wire radius	.001λ	-
[1] The fed dipole is located at Z = 0; positive Z is away from the reflector		

24

2. Disk Size and Location

The disk must be large enough to serve as an effective ground plane for the dipole. Generally the dipole height must be significantly less than the diameter of the disk. For the dipole and its image to add constructively in the direction of the reflector, the spacing should be approximately $.25\lambda$. The patterns for disk locations of $Z = +.1\lambda$, and $-.1\lambda$ are shown in Figures 11 and 12. All other feed parameters are held constant (values given in Table 4). The reflector diameter is 4.1λ and f/D = 0.5 in all cases. The high levels in the H plane patterns for $80° \leq \theta \leq 120°$ are due to feed spillover. A comparison of the figures shows that there is a tradeoff between spillover levels in the rear hemisphere $(90 \leq \theta \leq 180)$ and sidelobe levels in the forward hemisphere $(\theta \leq 90°)$. The impact of changing the disk radius by $.1\lambda$ is illustrated in Figures 13 and 14.

Relative Power, dB

0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50

---- H-Plane
—— E-Plane

0   20   40   60   80   100   120   140   160   180

θ, degrees
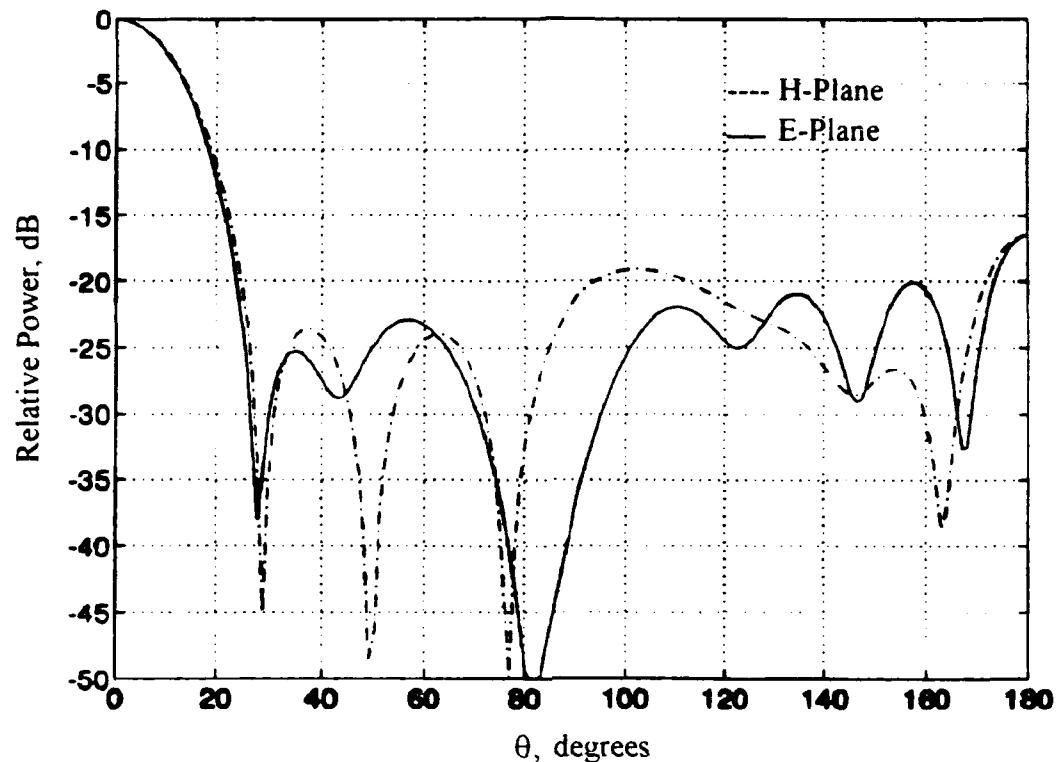
Figure 11. Radiation Pattern with Disk Shift of +0.1λ.

26
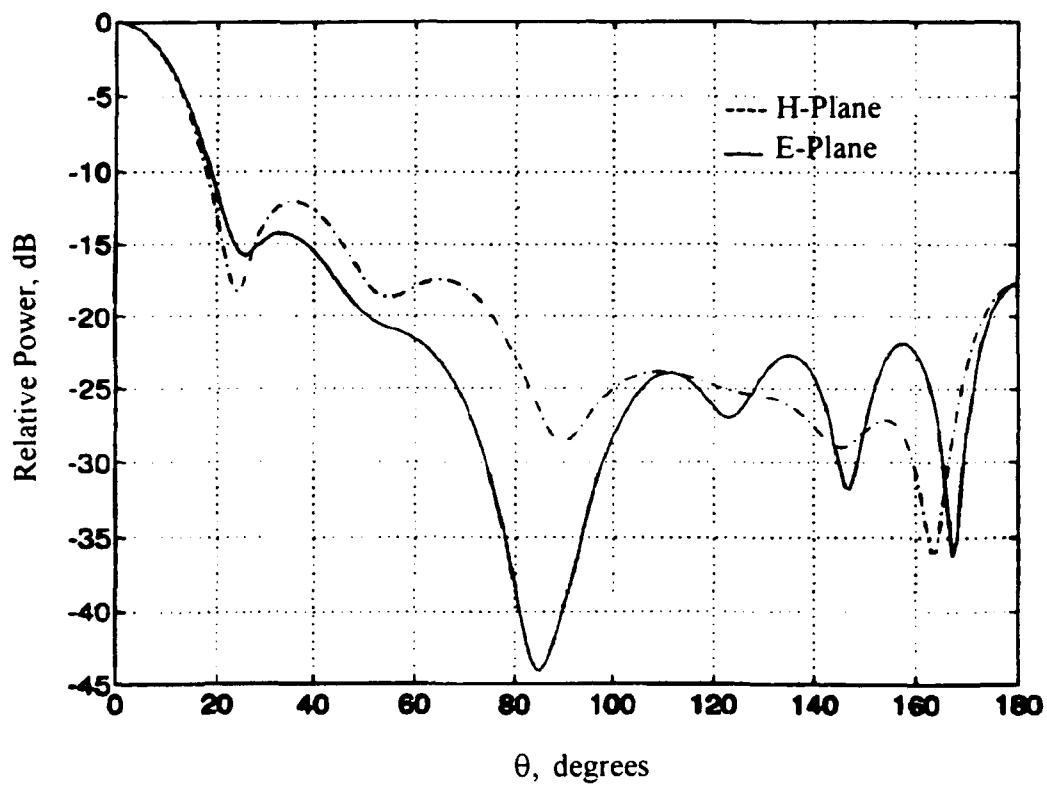
Figure 12. Radiation Pattern with Disk Shift of -0.1λ.
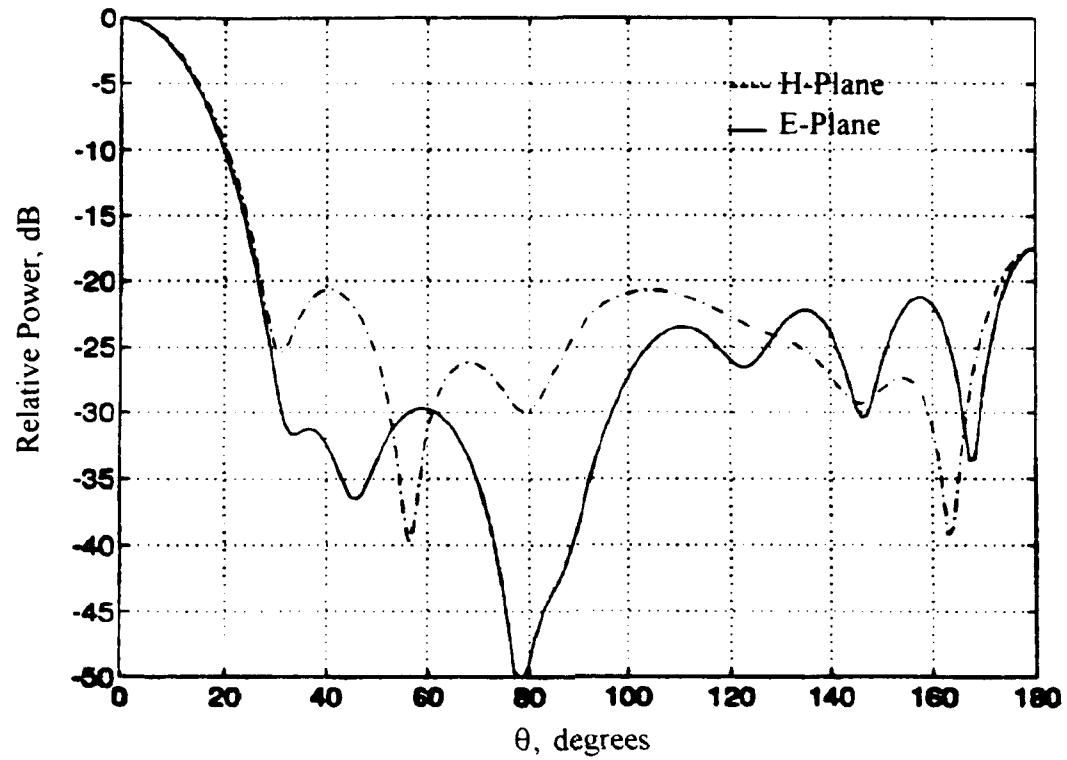
Figure 13. Radiation Pattern with Disk Size .1λ.
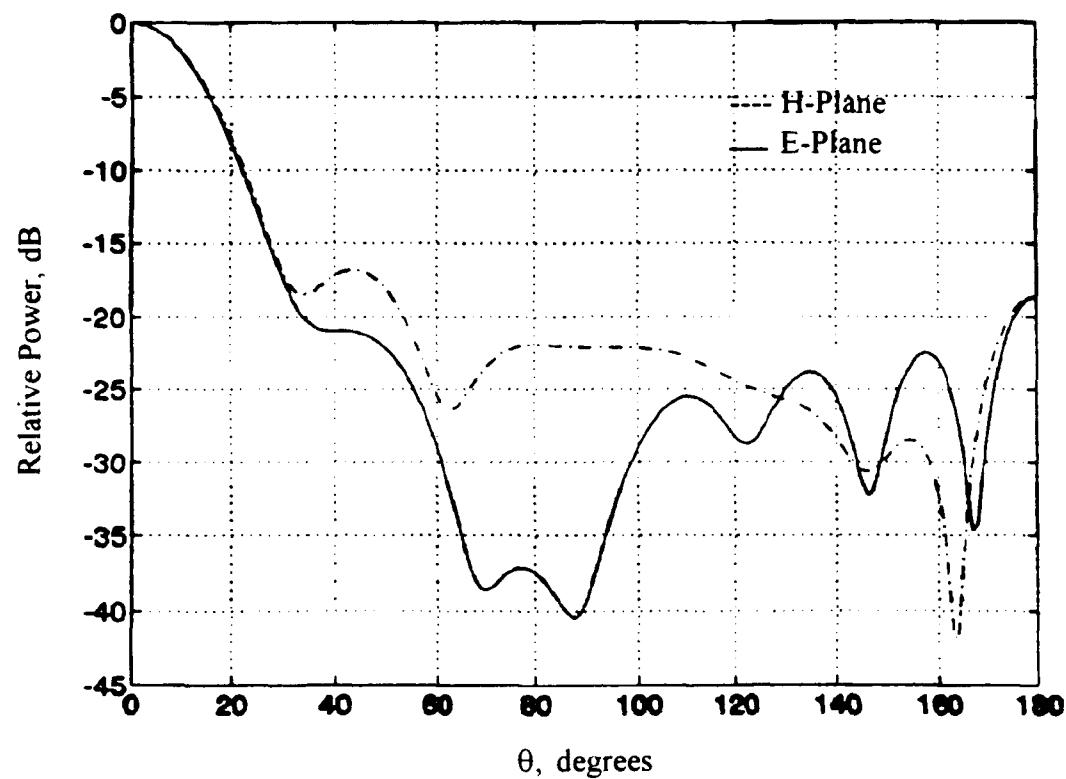
Figure 14. Radiation Pattern with Disk Reduced -.1λ.

3. Ring Size and Position

The beam-forming ring (BFR) compresses the H-plane beamwidth but leaves the E-plane beamwidth essentially unaffected. Thus the ring size and location can be used to equalize the feed beamwidth. Patterns for two ring radii are shown in Figures 15 and 16.

The ring acts somewhat like a director in a Yagi array when it is located in front of the dipole (towards the reflector) [Ref. 6]. When the ring is located behind the dipole it has little effect on the reflector scattered field. As illustrated in Figure 17 and 18, a shift of $.1\lambda$ results in about a 1 dB difference in the first sidelobe level.
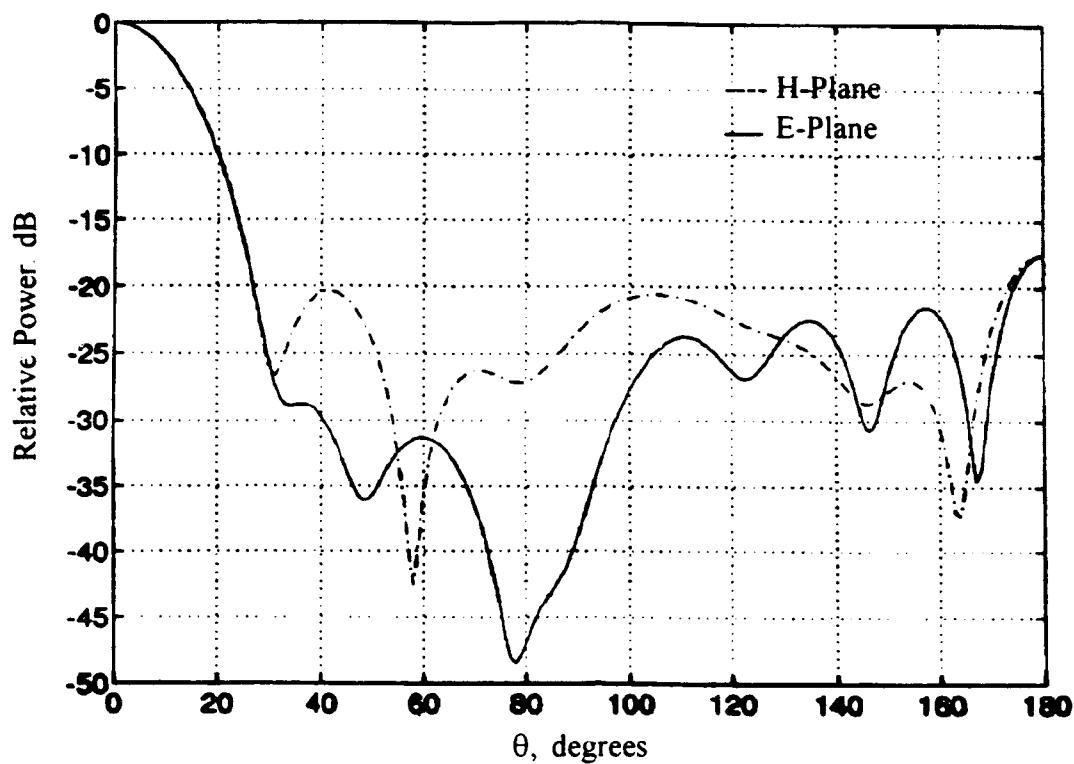
Figure 15. Radiation Pattern with Ring Size of 0.6λ.

31
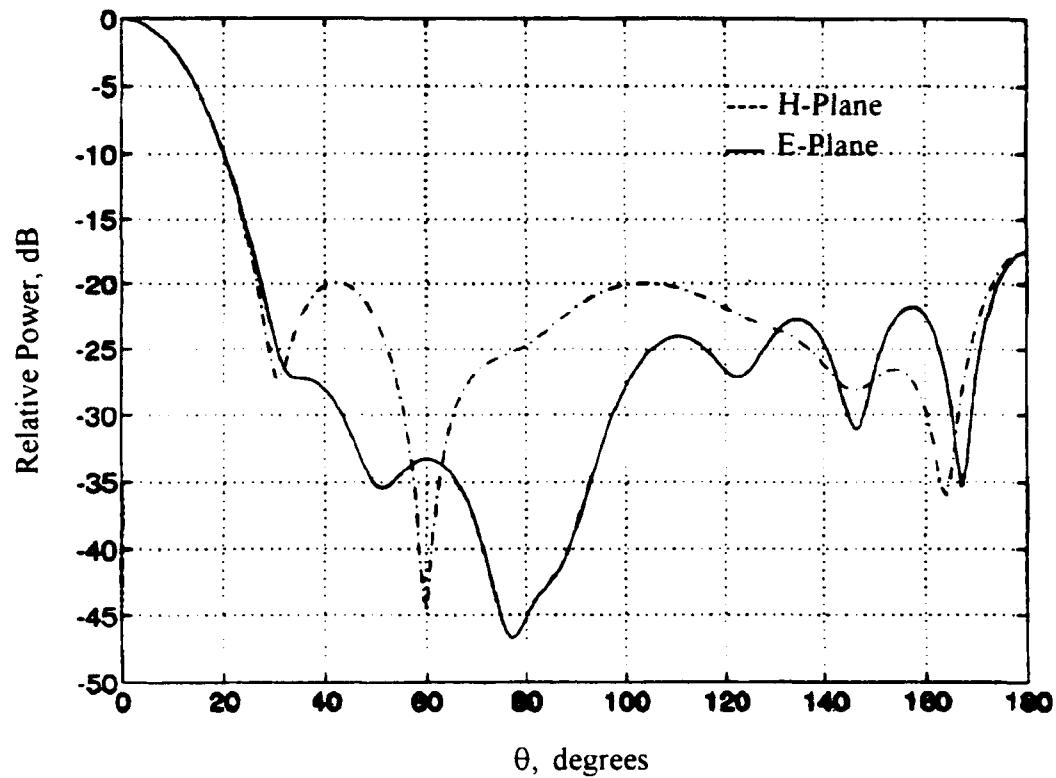
Figure 16. Radiation Pattern with Ring Size of 0.5λ.
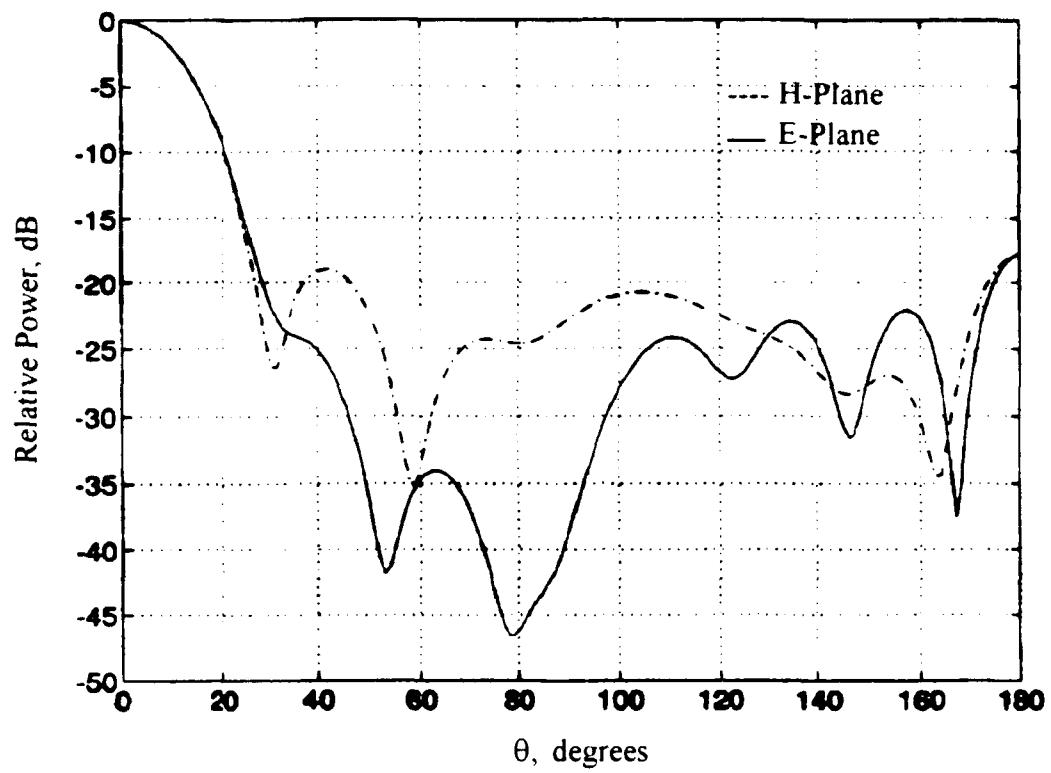
Figure 17. Radiation Pattern with Ring at Z = -0.2λ.
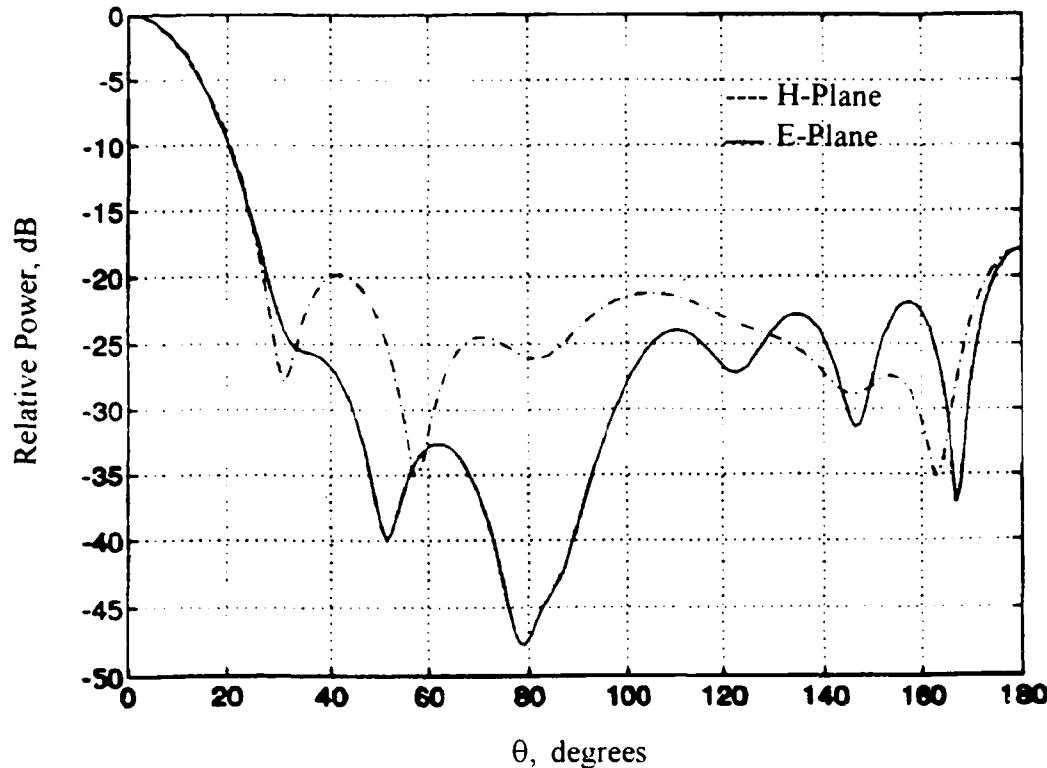
Figure 18. Radiation Pattern with Ring at Z = -0.1λ.

4. Adding a Parasitic Dipole

A parasitic dipole was added as a director in order to improve the directivity of

the feed and therefore increase the reflector edge taper. This method is effective in

narrowing the beamwidth of cavity-backed dipole antennas. In this case it was found that

changing the size and position of the parasitic element has no significant effect on the

performance of the antenna and does not offer any advantage. This is probably because

34

the parasitic dipole is not located within a cavity. Adding a second ring around the parasitic dipole could improve the performance. In an effort to keep the feed as simple as possible, the parasitic element was not considered further.

5. Defocusing the Feed

The phase center of the feed varies with frequency and angle, but is generally located between the fed dipole and disk. The antenna bandwidth can be increased by slightly displacing the feed from the reflector focus. Defocusing can cause a degradation at one frequency but an improvement at the other. Relative to an optimum pattern, defocusing will result in a spoiled beam; that is, null filling and change in beam slope. An example is shown in Figure 19. Defocusing also affects pattern levels in the rear hemisphere.

C. OPTIMUM DESIGNS

1. Single Frequency (1850 MHz)

After making all the comparisons mentioned earlier, an optimum configuration was identified for the 36 inch parabolic reflector operating at 1850 MHz. The patterns are shown in Figure 20, and the configuration parameters shown in Table 5.
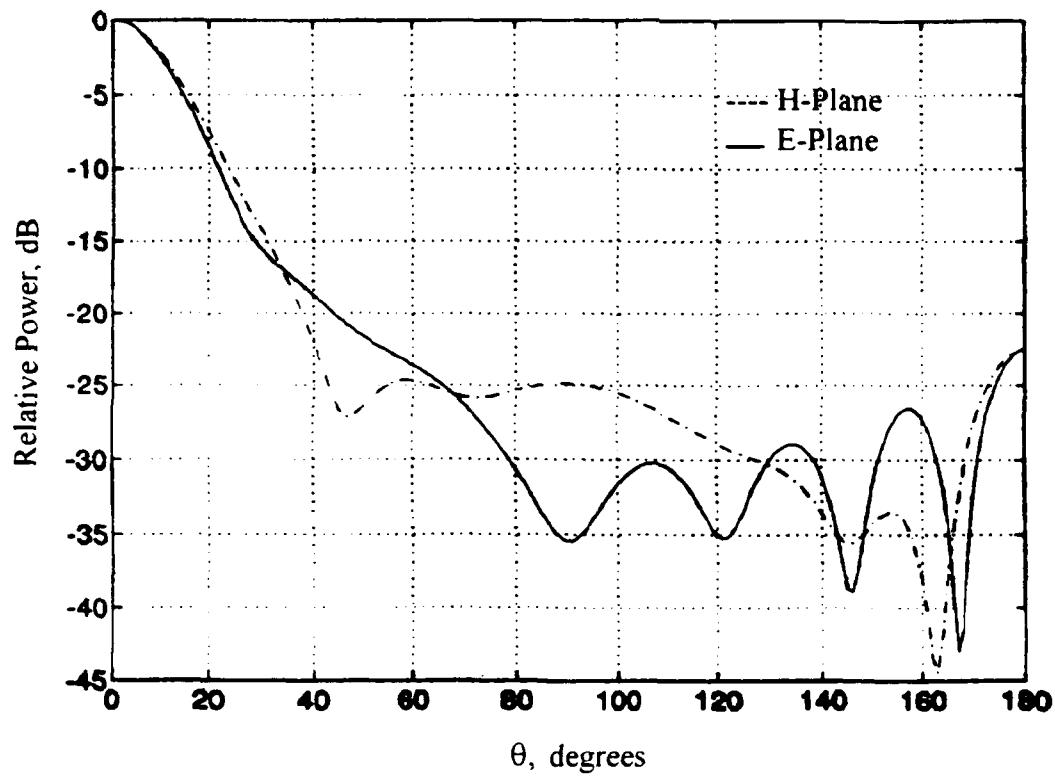
Figure 19. Radiation Pattern with Reflector Shifted 0.2λ in the Positive Direction To Defocus the Feed.

36
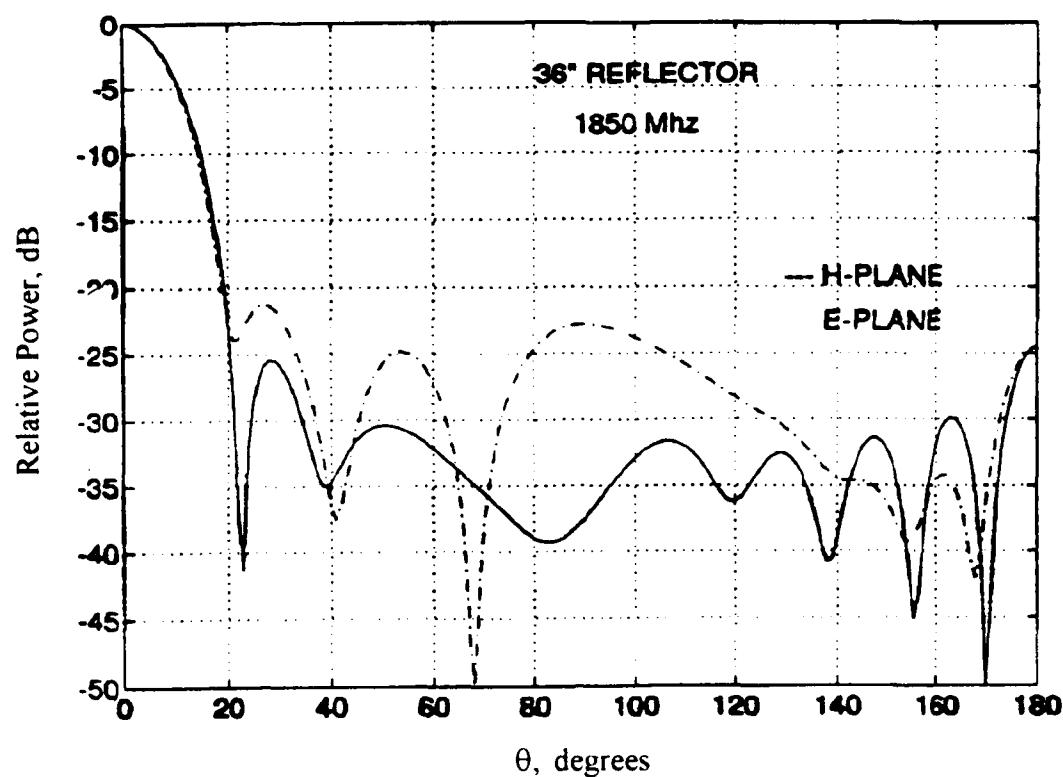
Figure 20. Radiation Pattern of Optimum Single Frequency Design for 36 inch Reflector (The Dimensions are given in Table 6).

TABLE 5. OPTIMUM GEOMETRY FOR 36 INCH REFLECTOR AT LOW FREQUENCY					
DM	=	4.1	DNL	=	0.48
DS	=	0.5	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.5	AW	=	0.001
ZR	=	0	ZSHIFT	=	0.2
SW	=	0.05			

This radiation pattern meets almost all the requirements listed in the Appendix A. The calculated total gain is $G = 20.7775$, which is sufficient, but the far out sidelobes are about 2 dB too high. Unfortunately this is a narrow band design and has poor performance at the lower frequency (1350 MHz) This design illustrates that achieving the specifications at a single frequency is relatively easy. However, broadbanding the antenna proves to be much more difficult.

2. Dual Frequency (1350 and 1850 MHz)

Starting from the configuration described in Table 4, attempts have been made to obtain a broadband design for the frequency range from 1350 to 1850 MHz. Figures 21 and 22 present the radiation patterns obtained for the 36 inch antenna which achieves most of the specifications given in the Appendix A. The gains are marginal at both frequencies and the beamwidth at the low frequency in too wide. Table 6 describes the configuration of this reflector.
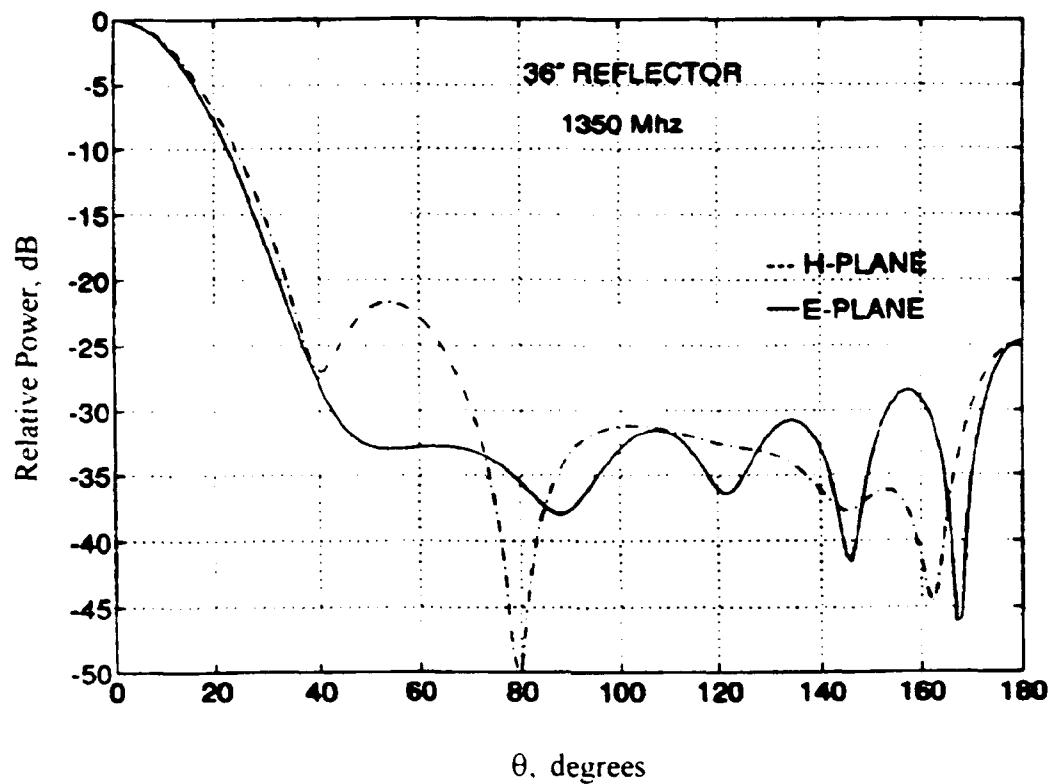
Figure 21. Radiation Pattern of 36 inch Reflector for Lower Frequency (1350 MHz). Dimensions are given in Table 6.
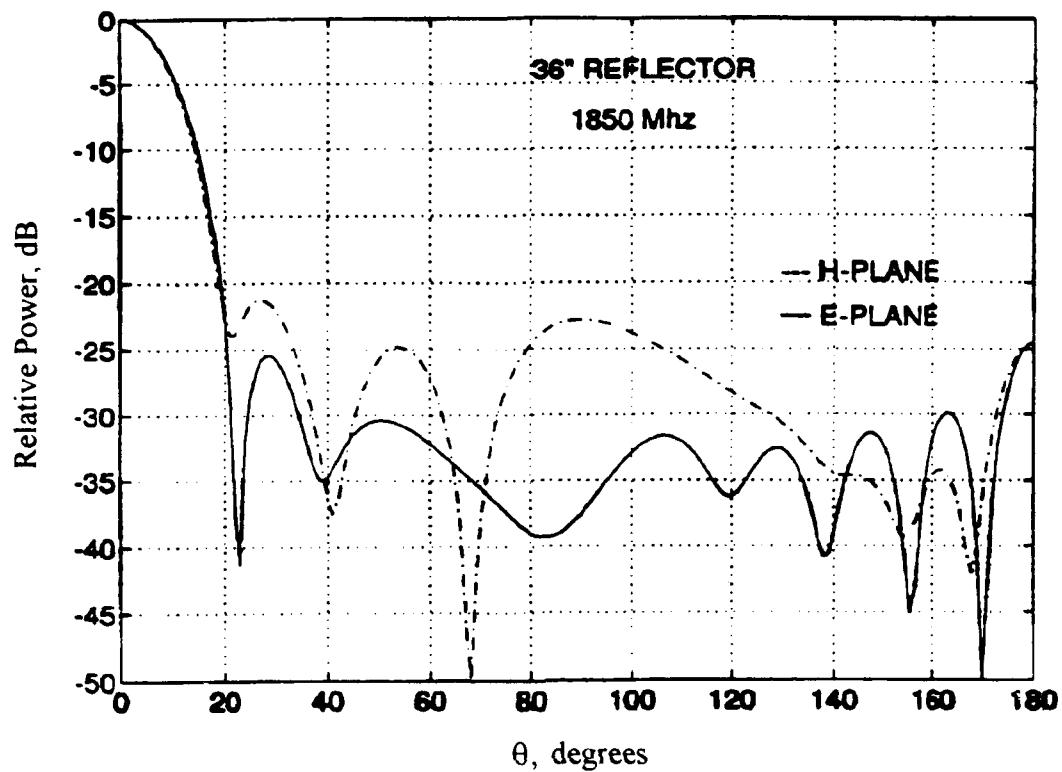
Figure 22. Radiation Pattern of 36 inch Reflector for Higher Frequency (1850 MHz).

40

TABLE 6. OPTIMUM GEOMETRY FOR 36 INCH REFLECTOR FOR THE LOW FREQUENCY					
DM	=	4.1	DNL	=	0.5
DS	=	0.6	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.6	AW	=	0
ZR	=	0.1	ZSHIFT	=	0.25
SW	=	0.05			

For the 48 inch antenna, Figures 23 and 24 show the radiation patterns for the optimum configuration whose dimensions are listed in Table 7.
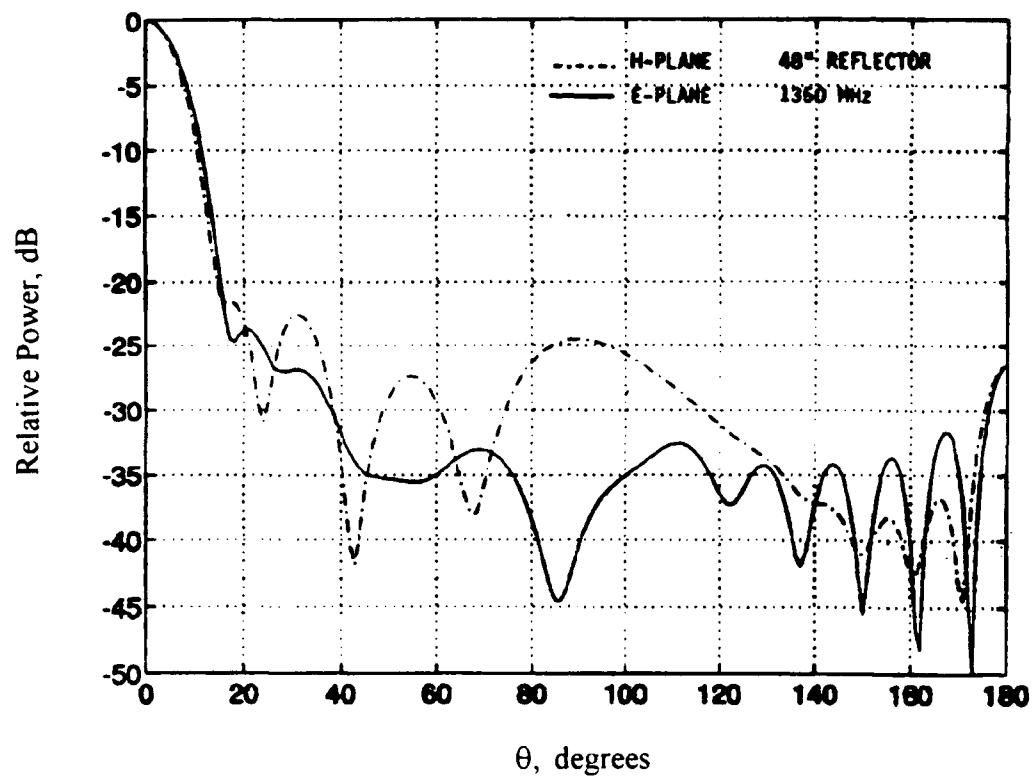
Figure 23. Radiation Pattern of 48 inch Reflector for Lower Frequency (1350 MHz).

42
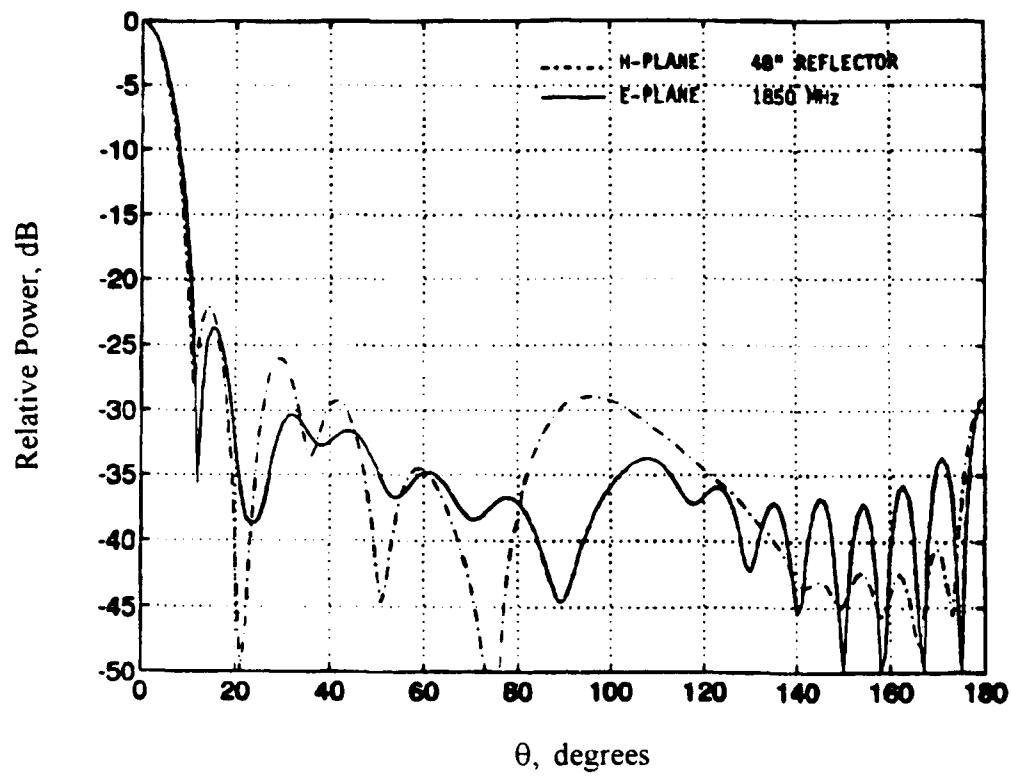
Figure 24. Radiation Pattern of 48 inch Reflector for Higher Frequency (1850 MHz).

43

TABLE 7. OPTIMUM GEOMETRY FOR 48 INCH REFLECTOR FOR HIGH FREQUENCY					
DM	=	7.5	DNL	=	0.48
DS	=	0.8	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.5	AW	=	0.001
ZR	=	0	ZSHIFT	=	0.2
SW	=	0.05			

It is worth noting that there is no feed configuration that can be used for both frequencies and simultaneously meet the specifications.

IV. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to find the optimum combination of the feed and reflector geometry over the frequency band 1350 to 1850 MHz. The current antenna size is 36 x 48 inches. Since the computer code only accepts circular reflector apertures, two separate circular antennas were analyzed. One was 36 inches and the second was 48 inches. The proposed feed design, which consists of a fed dipole in the vicinity of a parasitic ring and disk, was a good approach to achieve a significant improvement compared with the original geometry of the Marine radio AN/MRC-142. Because of its simplicity, the cost of the new feed represents a minimum impact on the system upgrade.

Calculations for both sizes were made separately and, as it is shown in Chapter III, the 36 inch reflector could not satisfy the requirements at both frequencies simultaneously, but it gave the best result for the high frequency (1850 MHz). The results obtained with the 48 inch reflector come very close to satisfying all the requirements, although the sidelobe level (SLL) is off by approximately 2 dB at wide angles in the H-plane.

An assumption with regard to the transmission line losses was made, which affect the total gain of the antenna. In the field calculations, solid surface reflection characteristics were assumed. In fact, the surface is a grid, and consequently the reflection coefficients for the θ and ϕ components of the electric field will vary with the

45

angle of incidence. This effect will be small if the wire spacing is small compared to λ.

Achieving the required gain was not a problem for the 48 inch design, and small adjustments in the antenna feed geometry did not have a significant negative impact on the antenna performance. It was also determined that if there was an improvement due to an additional parasitic dipole, the increase in complexity did not merit its use

To summarize, a low sidelobe reflector antenna has been designed which fulfilled most of the requirements for the Marine radio. The dipole disk feed with beam-forming ring is electrically and mechanically simple. It can be supported by means of a stiff coaxial cable aligned along the axis of the paraboloid, and held by a center support which offers minimum blockage when compared with the usual strut supports, as was stated by Kildal and Skyttemyer [Ref. 3].

APPENDIX A. ANTENNA SPECIFICATIONS

Over the frequency range of 1350-1850 MHz, the antenna must have gains as described in Figure A.
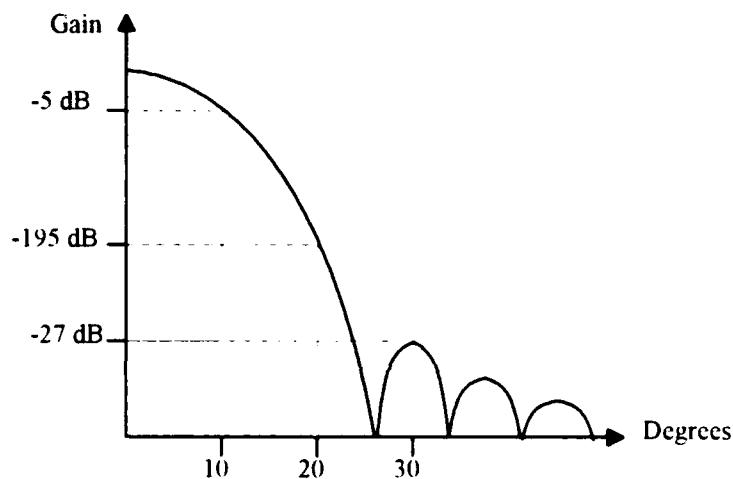
Azimuth Relative to Boresight (degrees)	Gain (dBi)
At 0	A - see note A
At ± 10	At least 5 dB lower than A
At ± 20	At least 19.5 dB lower than A
At ± 30 to 180	At least 27 dB lower than A

Shall satisfy the relationship $17.5 \leq A \leq 21$ dB

Figure A. Gain Requirements.

TABLE A. ANTENNA/MAST REFERENCE DATA	
Antennna	Lightweight, open grid, reflector
Frequency Range	1350 to 1850 MHz
Gain	
Frequency	
1350 MHz	18 dBi minimum
1850 MHz	20 dBi minimum
Breamwidth	+7.5°
Horizontal	
7½ ± 1° from boresight	3 dB half power
15 ± 1° from boresight	15 dB down
Sidelobes	10 dB min
Antennna	
Vertical	
7½ ± 1°, -2° from boresight	3 dB half power
15 ± 1°, -2° from boresight	15 dB down
Sidelobes	10 dB min
Polarization	Horizontal or vertical polarization
Weigth	17.5 lbs
Maximum Input Power	15 W
Maximum Output Power	2320 W Effective Radiated Power (ERP)
Reflector Dimensions	45 in X 35 in. Depth: 16 in
Mast	Telescoping mast, consists of eleven carbon-fiber tubular sections
Height	Continously adjustable from 5 ft 8 in to 50 ft
Length (for storage and transit)	5 ft 8 in
Maximum Height (deployed)	50 ft
Headload	37 lbs maximum
Maximum Wind (50 ft. erection)	60 mph (without ice) 40 mph (with ½ in ice loading)
Weight	35 lbs
2-Man Deployment Time	15 minutes
Mast Accessories Time	Stowage of mast accessories
	Total accessory bag weight: 44 lbs

APPENDIX B. PROGRAM CODE*

```
Gain2f


C PROGRAM mrcint.f
C
C FAR FIELD PATTERN INTEGRATION FOR GAIN
CALCULATIONS.
C *** general wire/bor geometries can be handled ***
C
C  >>>> INPUT FILE IS pcurrent - SPECIALIZED FOR
PROGRAM mrc.f
C  >>>> HAS A GAIN NORMALIZATION LOOP
INCORPORATED
C  >>>> WIRE DOES NOT HAVE TO LIE IN THE Z=0
PLANE
C
    DIMENSION
RH(1000),ZH(1000),AG(100),XG(100),XT(10),AT(10)
    DIMENSION
Q(30),S(30),nw1(2),nw2(2),pha(1000),xh(1000),yh(1000)
    COMPLEX
RS(1800),ETW,EPW,U,CNT(1500),ET1,EP1,ET2,EP2
    COMPLEX
CONJG,CMPLX,EXP1,EXP2,RW(2000),ET,EP,UC
    DATA pi/3.14159/
    data nt/2/,xt(1),at(1)/.5773503,1./
c   data
nt/4/,xt(1),xt(10),at(1),at(10)/.33998104,.8611363115,
c   * .6521451548,.3478548451/
    RAD=PI/180.
    BK=2.*PI
    U=(0.,1.)
    UC=-U/4./PI
    OPEN(1,FILE='outgaus')
    READ(1,*) NPHI
    NT2=NT/2
    DO 1 K=1,NT2
    K1=NT-K+1
    AT(K1)=AT(K)
    XT(K1)=XT(K)
  1 XT(K)=-XT(K)
    DO 3 K=1,NPHI
  3 READ(1,*) XG(K),AG(K)
    OPEN(3,file='pcurrent',STATUS='old')
    READ(3,*)
DM,AW,ZC,RC,DS,NP1,NP2,NBLOCK,NWIRES,FFAC
    READ(3,*)
NP,MT1,MP1,N,MT2,NSURF,NROW,MHI,MCDES
    write(6,*) 'NP1,NP2,N,MODES,NROW,NWIRES,NP='

    write(6,*) NP1,NP2,N,MODES,NROW,NWIRES,NP

    READ(3,*) (xh(i),i=1,np)
    READ(3,*) (yh(i),i=1,np)
    READ(3,*) (zh(i),i=1,np)
    READ(3,*) (rh(i),i=1,np)
    READ(3,*) (pha(i),i=1,np)
    READ(3,*) (nw1(i),i=1,nwires)
    READ(3,*) (nw2(i),i=1,nwires)
```

```
    READ(3,*) (cnt(i),i=1,nrow)
    CLOSE(3)
    NS=NBLOCK*N
    OPEN(8,FILE='outint')
    WRITE(8,8000) NP1,NP2,NBLOCK
8000 FORMAT(///,10X,'** WIRE/BOR ANTENNA GAIN
CALCULATION **',
    *//,10X,'NUMBER OF BOR POINTS (NP1)=',i4,/,10x,
    *'NUMBER OF DIPOLE POINTS (NP2)=',i4,/,10X,
    *'NUMBER OF MODE BLOCKS (2*M+1)=',i2)
    NDIVT=2
    NDIVP=2
    WRITE(6,*) 'ENTER NDIVT AND NDIVP'
    READ(5,*) NDIVT,NDIVP
    S1=0.
    S2=180.
    Q1=0.
    Q2=180.
    WRITE(6,*) 'THETA START AND STOP ANGLES
(DEGREES)'
    READ(5,*) S1,S2
    WRITE(6,*) 'THETA START AND STOP ANGLES
(DEGREES)'
    READ(5,*) Q1,Q2
C
C DEFINE STANDARD BOR INDICES
C
    MT1=NP1-2
    MP1=NP1-1
    MT2=NP2-2
C NWIRES=1 SINCE DUMMY SEGS WILL HAVE ZERO
CURRENT
    NWIRES=1
    NW1(1)=NP1+1
    NW2(1)=NP
C
C GAIN NORMALIZATION LOOP (USE THETA=PHI=0)
C
    ET1=(0.,0.)
    ET2=(0.,0.)
    ETW=(0.,0.)
    CALL
PLANEW(NWIRES,NW1,NW2,NP1,NP2,xh,yh,zh,0.,0.,RW)
    DO 610 L=1,MT2
610 ETW=ETW+RW(L)*CNT(L+NS)
    EXP1=(1.,0.)
    EXP2=CONJG(EXP1)
    DO 611 M=1,MHI
    NM=M-1
    CALL PLANES(NM,NP1,0,NT,RH,ZH,XT,AT,0.,RS)
    NTOP1=MODES-NM
    NTOP2=NBLOCK-(NTOP1+1)
    NS2=NTOP1*N
    NS1=NTOP2*N
    DO 612 L=1,MT1
    ET1=ET1+RS(L)*CNT(L+NS1)*EXP1
    IF(NM.EQ.0) GO TO 612
    ET1=ET1+RS(L)*CNT(L+NS2)*EXP2
```

---

* Although this is FORTRAN code, the column conventions are not observed for this listing so that space can be conserved.

```
  612  CONTINUE
       DO 613 L=1,MP1
       ET2=ET2+RS(L+MT1)*CNT(L+NS1+MT1)*EXP1
       IF(NM.EQ.0) GO TO 613
       ET2=ET2-RS(L+MT1)*CNT(L+NS2+MT1)*EXP2
  613  CONTINUE
  611  CONTINUE
       ET=UC*(ET1+ET2+ETW)
       EMAX=CABS(ET)
       WRITE(6,*) 'EMAX=',EMAX
       WRITE(8,8008) NT,NPHI,NDIVP,NDIVT,S1,S2,Q1,Q2
 8008 FORMAT(//,10X,'NT=',I3,/,10x,'NPHI=',I4,/,10X,
      * 'NUMBER OF INTEGRATION INTERVALS IN
  PHI=',I3,/,10x,
      * 'NUMBER OF INTEGRATION INTERVALS IN
  THETA=',I3,/,10x,
      * 'THETA LIMITS: START,STOP=',F7.2,2X,F7.2,/,10X,
      * 'PHI LIMITS: START,STOP=',F7.2,2X,F7.2)
  c
  c theta integration intervals
  c
       S1=S1*RAD
       S2=S2*RAD
       Q1=Q1*RAD
       Q2=Q2*RAD
       DS=(S2-S1)/FLOAT(NDIVT)
       DO 502 I=1,NDIVT+1
       S(I)=(I-1)*DS
       WRITE(6,*) 'I,S(I)=',I,S(I)
  502 CONTINUE
  c
  c phi integration intervals
  c
       DQ=(Q2-Q1)/FLOAT(NDIVP)
       DO 503 I=1,NDIVP+1
       Q(I)=(I-1)*DQ
       WRITE(6,*) 'I,Q(I)=',I,Q(I)
  503 CONTINUE
       SUM=0.
       do 2000 JJ=1,NDIVP
       P1=DQ/2.
       P2=(Q(JJ+1)+Q(JJ))/2.
       DO 2000 J=1,NPHI
       PHR=p1*xg(j)+p2
       DO 1000 II=1,NDIVT
       T1=DS/2.
       T2=(S(II+1)+S(II))/2.
       DO 1000 I=1,NPHI
       THR=T1*XG(I)+T2
       IF(THR.LT.PI) GO TO 510
       THR=(BK-THR)
       PHR=PHR+PI
  510 CONTINUE
       STRA=SIN(THR)*AG(I)*ag(j)
       ET1=(0.,0.)
       EP1=(0.,0.)
       ET2=(0.,0.)
       EP2=(0.,0.)
       ETW=(0.,0.)
       EPW=(0.,0.)
  C
  C WIRE CONTRIBUTION TO THE RADIATED FIELD
  C
       CALL
  PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,THR,P
  HR,RW)
       DO 210 L=1,MT2
       ETW=ETW+RW(L)*CNT(L+NS)
  210 EPW=EPW+RW(L+MT2)*CNT(L+NS)
  c
  c BOR SURFACE CONTRIBUTION TO THE RADIATED
  FIELD
  c
       DO 300 M=1,MHI
       NM=M-1
       EXP1=CEXP(CMPLX(0.,FLOAT(NM)*PHR))
       EXP2=CONJG(EXP1)
       CALL PLANES(NM,NP1,0,NT,RH,ZH,XT,AT,THR,RS)
       NTOP1=MODES-NM
       NTOP2=NBLOCK-(NTOP1+1)
       NS2=NTOP1*N
       NS1=NTOP2*N
       DO 250 L=1,MT1
       ET1=ET1+RS(L)*CNT(L+NS1)*EXP1
       EP1=EP1+RS(L+N)*CNT(L+NS1)*EXP1
       IF(NM.EQ.0) GO TO 250
       ET1=ET1+RS(L)*CNT(L+NS2)*EXP2
       EP1=EP1-RS(L+N)*CNT(L+NS2)*EXP2
  250 CONTINUE
       DO 260 L=1,MP1
       ET2=ET2+RS(L+MT1)*CNT(L+NS1+MT1)*EXP1
       EP2=EP2+RS(L+MT1+N)*CNT(L+NS1+MT1)*EXP1
       IF(NM.EQ.0) GO TO 260
       ET2=ET2-RS(L+MT1)*CNT(L+NS2+MT1)*EXP2
       EP2=EP2+RS(L+MT1+N)*CNT(L+NS2+MT1)*EXP2
  260 CONTINUE
  300 CONTINUE
       ET=UC*(ET1+ET2+ETW)
       EP=UC*(EP1+EP2+EPW)
       SUM=SUM+(CABS(ET)**2+CABS(EP)**2)*STRA
 1000 CONTINUE
 2000 CONTINUE
       PRAD=T1*P1*SUM
       GAIN=4.*PI*EMAX**2/PRAD
       GDB=10.*alog10(GAIN)
       WRITE(8,8010) PRAD,EMAX,GAIN,GDB
 8010 FORMAT(//,10X,'TOTAL RADIATED
  POWER=',E15.8,/,10X,
      * 'MAXIMUM FIELD VALUE (V/M)=',E15.8,/,10X.
      * 'GAIN=',E15.8,/,10x,'(dB)=',f8.2)
       WRITE(6,*) 'PRAD,GAIN,dB=',PRAD,GAIN,GDB
 9999 STOP
       END
       SUBROUTINE
  PLANES(M1,NP1,NP2,NT,RH,ZH,XT,AT,THR,R)
  C
  C PLANE WAVE EXCITATION VECTOR FOR BOR
  ELEMENTS.
  C NO CHANGE FROM HARRINGTON'S ORIGINAL
  PROGRAM OTHER THAN
  C ** ONLY ONE MODE PER CALL **
  C
       COMPLEX
  R(1800),U,U1,UA,UB,FA(50),FB(50),F2A,F2B,F1A,F1B
       COMPLEX U2,U3,U4,U5,CMPLX
       DIMENSION RH(1000),ZH(1000),XT(10),AT(10)
       DIMENSION R2(10),Z2(10),BJ(5000)
       U=(0.,1.)
```

```
U1=3.141593*U**M1
NF=1
M2=M1
NP=NP1+NP2
MP=NP-1
MT=MP-1
N=MT+MP
N2=2*N
CC=COS(THR)
SS=SIN(THR)
M3=M1+1
M4=M2+3
IF(M1.EQ.0) M3=2
M5=M1+2
M6=M2+2
DO 12 IP=1,MP
K2=IP
I=IP+1
DR=.5*(RH(I)-RH(IP))
DZ=.5*(ZH(I)-ZH(IP))
D1=SQRT(DR*DR+DZ*DZ)
R1=.25*(RH(I)+RH(IP))
IF(ABS(R1).LT.1.E-5) R1=1.
Z1=.5*(ZH(I)+ZH(IP))
DR=.5*DR
D2=DR/R1
DO 13 L=1,NT
R2(L)=R1+DR*XT(L)
Z2(L)=Z1+DZ*XT(L)
13 CONTINUE
D3=DR*CC
D4=-DZ*SS
D5=D1*CC
DO 23 M=M3,M4
FA(M)=0.
FB(M)=0.
23 CONTINUE
DO 15 L=1,NT
X=SS*R2(L)
IF(X.GT..5E-7) GO TO 19
DO 20 M=M3,M4
BJ(M)=0.
20 CONTINUE
BJ(2)=1.
S=1.
GO TO 18
19 M=2.8*X+14.-2./X
IF(X.LT..5) M=11.8+ALOG10(X)
IF(M.LT.M4) M=M4
BJ(M)=0.
JM=M-1
BJ(JM)=1.
DO 16 J=4,M
J2=JM
JM=JM-1
J1=JM-1
BJ(JM)=J1/X*BJ(J2)-BJ(JM+2)
16 CONTINUE
S=0.
IF(M.LE.4) GO TO 24
DO 17 J=4,M,2
S=S+BJ(J)
17 CONTINUE
24 S=BJ(2)+2.*S
18 ARG=Z2(L)*CC

UA=AT(L)/S*CMPLX(COS(ARG),SIN(ARG))
UB=XT(L)*UA
DO 25 M=M3,M4
FA(M)=BJ(M)*UA+FA(M)
FB(M)=BJ(M)*UB+FB(M)
25 CONTINUE
15 CONTINUE
IF(M1.NE.0) GO TO 26
FA(1)=- FA(3)
FB(1)=- FB(3)
26 UA=U1
DO 27 M=M5,M6
M7=M-1
M8=M+1
F2A=UA*(FA(M8)+FA(M7))
F2B=UA*(FB(M8)+FB(M7))
UB=U*UA
F1A=UB*(FA(M8)-FA(M7))
F1B=UB*(FB(M8)-FB(M7))
U4=D4*UA
U2=D3*F1A+U4*FA(M)
U3=D3*F1B+U4*FB(M)
U4=DR*F2A
U5=DR*F2B
K1=K2-1
K4=K1+N
K5=K2+N
R(K2+MT)=-D5*(F2A+D2*F2B)
R(K5+MT)=D1*(F1A+D2*F1B)
IF(IP.EQ.1) GO TO 21
R(K1)=R(K1)+U2-U3
R(K4)=R(K4)+U4-U5
IF(IP.EQ.MP) GO TO 22
21 R(K2)=U2+U3
R(K5)=U4+U5
22 K2=K2+N2
UA=UB
27 CONTINUE
12 CONTINUE
RETURN
END
SUBROUTINE
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,
* THR,PHR,R)
C
C  PLANE WAVE EXCITATION VECTOR ELEMENTS FOR
WIRE AND
C  ATTACHMENT SEGMENT. INCIDENCE DIRECTION IS
(THR,PHR).
C   - ONLY ONE INCIDENCE ANGLE PER CALL
C   - WIRE DOES NOT HAVE TO LIE IN THE Z=0 PLANE
C
COMPLEX
U0,AA,BB,C,R(400),CEXP,EXP,FI1,FI2,SI,DI,CMPLX
DIMENSION
ZH(400),NS(2),NW1(2),NW2(2),XH(400),YH(400)
MP2=NP2-1
MT2=NP2-2
MT22=2*MT2
DO 5 L=1,NWIRES
5 NS(L)=NW2(L)-NW1(L)+1
U0=(0.,0.)
CC=COS(THR)
SS=SIN(THR)
CP=COS(PHR)
```

```
      SP=SIN(PHR)                          C  Paraboloid WITH A PARASITIC RING DIPOLE FEED
      UP=SS*CP                             Fed dipole is at z=0.
      VP=SS*SP                             C  This program uses a parasitic dipole and two h-plane
      WP=CC                                C  parasitic dipoles and the subreflector. This system also
      DO 12 IP=1,MP2                       contains
      II=IP+NP1                            C  a cavity ring.
      I=II+1                               C
      ZS=.5*(ZH(I)+ZH(II))                 C  ICALC=0 CALC CURRENTS AND FIELD
      XS=.5*(XH(I)+XH(II))                 C    =1 CALC FIELDS ONLY (READ CURRENTS)
      YS=.5*(YH(I)+YH(II))                 C   IMP=0 PEREECTLY CONDUCTING SURFACES
      DX=XH(I)-XH(II)                      C    =1 SOME NONZERO SURFACE RESISTANCE
      DY=YH(I)-YH(II)                      C  ICWRT=0 WRITE CURRENT COEFFICIENCTS TO
      D1=SQRT(DX**2+DY**2)                 FILE pcurrent
      SU=DY/D1                             C   IRES=0 READ RESISTIVE CORRECTIONS
      CU=DX/D1                             C
C FOR WIRES IN PERPENDICULAR TO Z SIN(V)=1 AND    COMPLEX
COS(V)=0                                  EP,ET,Z(500000),RS(1000),RW(400),E(700),C(700),U,UC
      SV=1.0                                  COMPLEX ZL0(400),ZL(1500),EC,EX,ZSS(50000)
      CV=0.0                                  COMPLEX EXP1,EXP2,ZSW(50000),ZWW(10000)
C                                             COMPLEX
C WIRE SEGMENT CALCULATIONS                CEXP,CONJG,CMPLX,ET1,ET2,EP1,EP2,ETW,EPW
C                                             DIMENSION
      A=UP*CU+VP*SU                        RH(400),ZH(400),XT(4),AT(4),IPS(700),NW1(4),NW2(4)
      B=UP*XS+VP*YS+WP*ZS                     DIMENSION
      C=CMPLX(0.,A)                        A(400),X(400),EXP(800),ANG(800),ECP(800)
      EXP=CEXP(CMPLX(0.,B))                   DIMENSION ECV(800),EXV(800),PHC(800),PHX(800)
      AA=CC*(CU*CP+SU*SP)                     DIMENSION
      BB=SU*CP-SP*CU                       XX(41),YY(41),XH(400),YH(400),PHA(400)
      PSI=D1*A/2.                             DATA
      IF(PSI.NE.0.) GO TO 60               PI,START,STOP,DT/3.14159,0.,180.,1./,ICWRT/0/,IRES 1
      SINC=1.                                 DATA ICALC/0/,IPRINT/0/,IMP/0/,ITEST/1/
      GO TO 61                                DATA nt/2/,xt(1),at(1)/.5773503,1./
 60   SINC=SIN(PSI)/PSI                    c    data nt/4/,xt(1),xt(2),at(1),at(2)/.33998104,.8611363115,
 61   COSP=COS(PSI)                        c    *.6521451548,.3478548451/
      FI1=SINC*D1*EXP/2.                      OPEN(1,FILE='outgaus',status='old')
      FI2=(0.,0.)                             OPEN(30,FILE='rh.m')
      IF(ABS(A).LT.1.E-4) GO TO 62            OPEN(31,FILE='zh.m')
      CSP=COSP-SINC                           READ(1,*) NPHI
      IF(ABS(CSP).LT.1.E-4) GO TO 62          DO 3 K=1,NPHI
      FI2=EXP/C*CSP                           READ(1,*) X(K),A(K)
 62   CONTINUE                             3 CONTINUE
      SI=FI1+FI2                              RAD=PI/180.
      DI=FI1-FI2                              BK=2.*PI
C                                             U=(0.,1.)
C R-WIRE-THETA                                U0=(0.,0.)
C                                             UC=-U/4./PI
      IF(IP.EQ.MP2) GO TO 10                  NT2=NT/2
      R(IP)=AA*SI                             DO 1 K=1,NT2
      R(IP+MT2)=BB*SI                         K1=NT-K+1
 10   CONTINUE                                AT(K1)=AT(K)
C                                             XT(K1)=XT(K)
C R-WIRE-PHI                               1 XT(K)=-XT(K)
C                                          C
 14   IF(IP.EQ.1) GO TO 12                 C NP10 = NUMBER OF PARABOLOID POINTS
      R(IP-1)=R(IP-1)+AA*DI                C NP11 = NUMBER OF DISC POINTS
      R(IP-1+MT2)=R(IP-1+MT2)+BB*DI        C NP12 = NUMBER OF RING POINTS
 12   CONTINUE                             C
      RETURN                                  MODES=1
      END                                     MHI=MODES+1
                                              NBLOCK=2*MODES+1
                                              NWIRES=1
Reflector                                     WRITE(6,*) 'ENTER START,STOP,DT'
                                              READ(5,*) START,STOP,DT
C  PROGRAM  mrc.f  (Marine Radio Antenna Program)    NP10=61
C                                             NP11=31
c  Modified from ORDONEZ.f -- hyperboloid becomes a disc    NP11=31
```

52

```fortran
      NP12=3
      WRITE(6,*) 'ENTER PARA (NP10), DISC (NP11) AND
     RING (NP12) PTS'
      READ(5,*) NP10,NP11,NP12
      NP1=NP10+NP11+NP12
C
C DM=MAIN REFLECTOR DIAMETER
C DS=DISC (SUBREFLECTOR) DIAMETER
C ZC=DISC LOCATION ALONG Z AXIS
C FOD=f/DM RATIO
C RC=RADIUS OF THE RING
C SW=RING (STRIP) WIDTH
C
      DM=5.0
      R0=DM/2.
      DS=1.1
      ZC=.25
      FOD=.3
      RC=0.5
      SW=.05
      WRITE(6,*) 'ENTER DM, DS, ZC (>0), FOD, RC, ZR
     AND SW'
      READ(5,*) DM,DS,ZC,FOD,RC,ZR,SW
      FM=FOD*DM
      WRITE(6,*) 'ENTER ZSHIFT FOR PARABOLOID'
      READ(5,*) ZSHIFT
C
C GENERATE PARABOLOID CONTOUR
C
      PHIV=2.*ATAN(1./4./FOD)
      FNM=FLOAT(NP10-1)
      DO 50 I=1,NP10
      TH=FLOAT(I-1)*PHIV/FNM
      RM=2.*FM/(1.+COS(TH))
      XH(I)=0.
      YH(I)=0.
      ZH(I)=-RM*COS(TH)*BK+ZSHIFT*BK
      RH(I)=RM*SIN(TH)*BK
      PHA(II)=0.
  50  CONTINUE
C
C DISC LOCATED A Z=ZC
C
      DSK=DS/2./FLOAT(NP11-1)
      DO 5 I=1,NP11
      II=I+NP10
      XH(II)=0.
      YH(II)=0.
      ZH(II)=ZC*BK
      RH(II)=FLOAT(I-1)*DSK*BK
      PHA(II)=0.
  5   CONTINUE
C
C NEXT THE SIDEWALLS
C
      DSW=SW/FLOAT(NP12-1)
      ZRBK=ZR*BK
      IF(NP12.NE.0) THEN
      DO 7 I=1,NP12
      II=NP11+NP10+I
      XH(II)=0.
      YH(II)=0.
      RH(II)=RC*BK
      ZH(II)=FLOAT(I-1)*DSW*BK+ZRBK
  7   PHA(II)=0.

      ENDIF
      NP1=NP10+NP11+NP12
C
C DIPOLE ANTENNA POINTS IN WAVELENGTHS:  AW=
     RADIUS; NP2= NUMBER
C OF POINTS (=NP21+NP22; NP21 MUST BE ODD).
     DLGTH= LENGTH;
C PLGTH IS PARASITIC ELEMENT LENGTH.
C
      AW=.001
      DLGTH=.45
      PLGTH=.44
      WRITE(6,*) 'ENTER DLN, PLN, DDIP, ROT AND AW'
      WRITE(6,*) '(DDIP<0 IS TOWARD PARABOLOID)'
      READ(5,*) DLGTH,PLGTH,DDIP,ROT,AW
      CENT=DLGTH/2.
      AK=AW*BK
      NP21=11
      NP22=0
      WRITE(6,*) 'ENTER NP21 AND NP22 (ONLY 1 DIP IF
     NP22=0)'
      READ(5,*) NP21,NP22
      NW1(1)=NP1+1
      NW2(1)=NP1+NP21
      NP2=NP21+NP22
      DEL=DLGTH/FLOAT(NP21-1)
      DO 10 I=1,NP21
      II=NP1+I
      YH(II)=0.
      ZH(II)=0.
      XH(II)=BK*(FLOAT(I-1)*DEL-CENT)
      RH(II)=SQRT(XH(II)**2+YH(II)**2)
      PHA(II)=ATAN2(YH(II),XH(II)+1.E-6)
  10  CONTINUE
      IF(NP22.NE.0) THEN
      NWIRES=2
      NW1(2)=NP1+NP21+1
      NW2(2)=NP1+NP21+NP22
      DEL=PLGTH/FLOAT(NP22-1)
      CENT=PLGTH/2.
      DO 11 I=1,NP22
      II=NP1+NP21+I
      ZH(II)=DDIP*BK
      XH(II)=BK*(FLOAT(I-1)*DEL-CENT)*COS(ROT*RAD)
      YH(II)=BK*(FLOAT(I-1)*DEL-CENT)*SIN(ROT*RAD)
      RH(II)=SQRT(XH(II)**2+YH(II)**2)
      PHA(II)=ATAN2(YH(II),XH(II)+1.E-6)
  11  CONTINUE
      ENDIF
C NP23=NUMBER OF H-PLANE DIPOLE POINTS
C HLGTH=H-PLANE DIPOLE LENGTH
C DHP=H-PLANE DIPOLE DISTANCE FROM FEED
C ZHP=H-PLANE DIPOLE Z COORDINATE
C NP24=NUMBER OF POINTS FOR THE OTHER
     H-PLANE DIPOLE
      NP23=7
      NP24=7
      HLGTH=.2
      DHP=.2
      ZHP=.001
      WRITE(6,*) 'ENTER NUMBER OF POINTS PER
     H-PLANE DIPOLE'
      WRITE(6,*) '(0 FOR NO H-PLANE PARASITIC
     DIPOLES)'
      READ(5,*) NP23
```

53

```
        IF(NP23.NE.0) THEN                          * 'H-PLANE DIPOLE DISTANCE FROM
        WRITE(6,*) 'H-PLANE DIPOLE LENGTH, DISTANCE  AXIS=',F8.3,/,5X,
AND LOCATION'                                       * 'Z POSITION OF H-FIELD
        READ(5,*) HLGTH DHP,ZHP                     DIPOLE=',F8.3,/,5X,'NUMBER OF H-FIELD
        NWIRES=NWIRES+2                             * 'DIPOLE POINTS=',I3)
        NP24=NP23                                   IF(ISEG.EQ.0) WRITE(8,1300)
        NP2=NP21+NP22+NP23+NP24                     1300
        NW1(3)=NP1+NP21+NP22+1                       FORMAT(/,5X,'INDEX',8X,'Z(I)',10X,'RHO(I)',8x,'ZSURF')
        NW2(3)=NP1+NP21+NP22+NP23                   C
        NW1(4)=NP1+NP21+NP22+NP23+1                 C FILE difdat CONTAINS RESISTIVE CORRECTIONS IF
        NW2(4)=NP1+NP21+NP22+NP23+NP24              IRES.NE.0
        DEL=HLGTH/FLOAT(NP23-1)                     C
        CENT=HLGTH/2.                               IF((IMP.EQ.0).OR.(IRES.NE.0)) GO TO 70
        DO 12 I=1,NP23                              OPEN(9,FILE='difdat')
        I1=NP1+NP21+NP22+I                          READ(9,*) ID
        ZH(I1)=ZHP*BK                               WRITE(6,*) 'ID=',ID
        YH(I1)=DHP*BK                               DO 75 I=1,ID
        XH(I1)=BK*(FLOAT(I-1)*DEL-CENT)             READ(9,*) II,RI,YY(I),DUM
        RH(I1)=SQRT(XH(I1)**2+YH(I1)**2)            IF(YY(I).LT.0.) YY(I)=0.
        PHA(I1)=ATAN2(YH(I1),XH(I1)+1.E-6)          75   CONTINUE
        I2=I1+NP23                                  XXI=1./FLOAT(ID-1)
        ZH(I2)=ZHP*BK                               DO 15 II=1,ID
        YH(I2)=-DHP*BK                              XX(II)=XXI*FLOAT(II-1)
        XH(I2)=BK*(FLOAT(I-1)*DEL-CENT)             15   CONTINUE
        RH(I2)=SQRT(XH(I2)**2+YH(I2)**2)            WRITE(6,*) 'SURFACE IMPEDANCE VALUES READ'
        PHA(I2)=ATAN2(YH(I2),XH(I2)+1.E-6)          70   CONTINUE
12   CONTINUE                                       DO 52 I=1,NP1
        ENDIF                                       IF(ABS(ZH(I)).LT..001) ZH(I)=0.
        CLOSE(1)                                    IF(ABS(RH(I)).LT..001) RH(I)=0.
        NP=NP1+NP2                                  ZL0(I)=(0.,0.)
        WRITE(6,*) 'ENTER FREQUENCY FACTOR'         XH(I)=XH(I)*FFAC
        READ(5,*) FFAC                              YH(I)=YH(I)*FFAC
        OPEN(8,file='outmrc')                       ZH(I)=ZH(I)*FFAC
        WRITE(8,8000)                               RH(I)=RH(I)*FFAC
DM,DS,FOD,PHIV/RAD,NP10,NP11,RC,SW,                 ZHB=ZH(I)/BK
    .                                               RHB=RH(I)/BK
NP12,ZSHIFT,DLGTH,PLGTH,DDIP,NP2,AW,MODES,NT,       WRITE(30,5019) RHB
NPHI,FFAC                                           WRITE(31,5019) ZHB
        IF(NP23.NE.0) WRITE(8,8001) HLGTH,DHP,ZHP,NP23   c   if(rhb.ge.10.) zl0(i)=(.2,0.)
8000 FORMAT(//,5X,'*** MARINE RADIO REFLECTOR       C
ANTENNA ***',//,5X,                                C NONZERO SURFACE IMPEDANCES IF IMP > 0
        *'REFLECTOR PARAMETERS (LENGTHS IN         C
WAVELENGTHS):',/,5X,                               IF((IMP.EQ.0).OR.(IRES.NE.0)) GO TO 51
        *'MAIN REFL DIA=',F8.3,/,5X,'DISC          IF(I.GT.NP10) GO TO 51
DIA=',F8.3,/,5X,'F/D=',F8.4,                        C
        * /,5X,'PHIV (DEG)=',F8.2,/,5X,'MAIN REFL POINTS   C USE THE EXACT RESISTIVE CORRECTIONS --
(NP11)=',I4,/,                                      INTERPOLATE BETWEEN
        * 5X,'SUB REFL POINTS (NP12)=',I4,/,5X,/,5X,   C DATA POINTS.
        * 'RING RADIUS=',F8.3,/,5X,'SIDEWALL       C
LENGTH=',F8.3,/,5X,                                 UU=RHB/R0
        * 'NUMBER OF RING POINTS (NP12)=',I4,//,5X,   CALL INTERP(UU,VV,XX,YY,ID)
        * 'PARABOLOID SHIFT DISTANCE,             ZL0(I)=VV
ZSHIFT=',F8.3,/,5X,                                 51 CONTINUE
        * 'DIPOLE PARAMETERS:',/,5X,'FED DIPOLE     WRITE(8,8004) I,ZHB,RHB,ZL0(I)
LENGTH=',F8.3,/,5X,                                 52 CONTINUE
        * 'PARASITIC DIPOLE                        8004 FORMAT(6X,I4,4X,F8.3,8X,F8.3,6X,2F8.4)
LENGTH=',F8.3,/,5X,'SPACING=',F8.3,/,5X,            WRITE(8,1310)
        * 'NUMBER OF DIPOLE POINTS =',I4,/,5X,'RADIUS OF   1310 FORMAT(/,5X,'DIPOLE COORDINATES:',//,
DIPOLE=',                                           * 5X,'INDEX',8X,'Z(I)',10X,'RHO(I)',10X,'PHI PLN')
        * F8.4,//,5X,'NUMBER OF AZIMUTHAL          DO 53 I=NP1+1,NP
MODES=',I3,/,5X,'NT=',I3,                           IF(ABS(ZH(I)).LT..001) ZH(I)=0.
        * /,5X,'NPHI=',I3,/,5X,'FREQ. SCALE FACTOR=',F8.4)   IF(ABS(RH(I)).LT..001) RH(I)=0.
8001 FORMAT(/,5X,'H-PLANE DIPOLE                    XH(I)=XH(I)*FFAC
LENGTH=',F8.3,/,5X,                                 YH(I)=YH(I)*FFAC
                                                    ZH(I)=ZH(I)*FFAC
```

54

```
      RH(I)=RH(I)*FFAC
      PHB=PHA(I)/RAD
      ZHB=ZH(I)/BK
      RHB=RH(I)/BK
      WRITE(30,5019) RHB
      WRITE(31,5019) ZHB
   53 WRITE(8,8005) I,ZHB,RHB,PHB
 8005 FORMAT(6X,I4,4X,F8.3,8X,F8.3,9X,F8.2)
  799 CONTINUE
      IF(ITEST.EQ.0) GO TO 9998
      write(6,*) 'geometry defined'
C
C DEFINE DIMENSIONS OF THE IMPEDANCE MATRIX
BLOCKS
C
      MT1=NP1-2
      MP1=NP1-1
      N=MP1+MT1
      MT2=NP2-2
      NSURF=NBLOCK*N
      NSW=NSURF+MT2
      NROW=NSW
      WRITE(6,*)
'NP1,NP2,NSURF,NROW=',NP1,NP2,NSURF,NROW
      WRITE(6,*) 'MT2 SHOULD BE ODD -- MT2=',MT2
      IF(ITEST.EQ.0) GO TO 9998
      IF(ICALC.EQ.0) THEN
C
C COMPUTE IMPEDANCE MATRIX ELEMENTS
C
      CALL
ZMATWW(NWIRES,NW1,NW2,XH,YH,RH,ZH,NT,XT,AT,A
K,ZWW)
      CALL ZASMB0(NP1,NP2,MODES,Z,ZWW)
      write(6,*) 'wire impedance computed'
      IF(IMP.NE.0) THEN
      CALL ZLOAD(NP1,RH,ZH,ZL0,ZL)
      WRITE(6,*) 'RESISTIVE SURFACE IMPEDANCE
MATRIX COMPUTED'
      ENDIF
      DO 400 M=1,MHI
      NM=M-1
      CALL
ZMATSS(NM,NM,NP10,NP11,NP12,NPHI,NT,RH,ZH,X,A,X
T,AT,ZSS)
      IF(IMP.NE.0) CALL ZTOT(MT1,MP1,ZL,ZSS)
      CALL
ZMATSW(NWIRES,NW1,NW2,NP10,NP11,NP12,XH,YH,R
H,ZH,
     * NT,XT,AT,NPHI,X,A,NM,AK,ZSW)
      CALL ZASMBN(NP1,NP2,MODES,NM,Z,ZSS,ZSW)
      IF(NM.EQ.0) GO TO 400
      NMN=-NM
      CALL
ZMATSW(NWIRES,NW1,NW2,NP10,NP11,NP12,XH,YH,R
H,ZH,
     * NT,XT,AT,NPHI,X,A,NMN,AK,ZSW)
      CALL ZASMBN(NP1,NP2,MODES,NMN,Z,ZSS,ZSW)
  400 CONTINUE
      write(6,*) 'z filled'
      CALL DECOMP(NROW,IPS,Z)
      write(6,*) 'z decomposed'
C
C EXCITATION ELEMENTS (NONZERO FOR THE
DIPOLE ONLY)
C
      DO 40 I=1,NROW
   40 B(I)=(0.,0.)
      I0=NSURF+(NP21-1)/2
      B(I0)=(1.,0.)
      CALL SOLVE(NROW,IPS,Z,B,C)
      write(6,*) 'current coefficients computed'
c      do 665 ii=1,nrow
c665   write(6,*) ii,c(ii)
      IF((ICWRT.EQ.0).AND.(ICALC.EQ.0)) THEN
C
C WRITE CURRENTS ON DISC FOR PATTERN
INTEGRATION
c (program 'cavarchint.f')
C
      OPEN(3,file='pcurrent')
      WRITE(3,*)
DM,AW,ZC,RC,DS,NP1,NP2,NBLOCK,NWIRES,FFAC
      WRITE(3,*)
NP,MT1,MP1,N,MT2,NSURF,NROW,MHI,MODES
      WRITE(3,*) (XH(I),I=1,NP)
      WRITE(3,*) (YH(I),I=1,NP)
      WRITE(3,*) (ZH(I),I=1,NP)
      WRITE(3,*) (RH(I),I=1,NP)
      WRITE(3,*) (PHA(I),I=1,NP)
      WRITE(3,*) (NW1(I),I=1,NWIRES)
      WRITE(3,*) (NW2(I),I=1,NWIRES)
      WRITE(3,*) (C(I),I=1,NROW)
      ENDIF
      ENDIF
C
C IF ICALC.NE.0 THEN READ CURRENT COEFFICIENTS
FROM DISK FILE
C
      IF(ICALC.NE.0) THEN
      OPEN(3,file='pcurrent',STATUS='OLD')
      READ(3,*)
DMX,AWX,ZCX,RCX,DSX,NP1X,NP2X,NBLX,NWX
      READ(3,*)
NPX,MT1X,MP1X,NX,MT2X,NSX,NRX,MHIX,MODESX
      READ(3,*) (xh(i),i=1,np)
      READ(3,*) (yh(i),i=1,np)
      READ(3,*) (zh(i),i=1,np)
      READ(3,*) (rh(i),i=1,np)
      READ(3,*) (pha(i),i=1,np)
      READ(3,*) (nw1(i),i=1,nwires)
      READ(3,*) (nw2(i),i=1,nwires)
      READ(3,*) (c(i),i=1,nrow)
      CLOSE(3)
      write(6,*) 'data read from pcurrent'
      do 909 i=1,np
  909 write(6,*) 'i,rh,zh=',i,rh(i)/bk,zh(i)/bk
      ENDIF
      IT=INT((STOP-START)/DT)+1
C
C RECEIVER PHI CUTS: DO 0 AND 90 (E- AND H-
PLANES)
C
      DO 501 IP=1,2
      ECX=1.e-10
      PHR0=0.
      IF(IP.EQ.2) PHR0=RAD*90.
      DO 500 I=1,IT
      THETA=FLOAT(I-1)*DT+START
      THR=THETA*RAD
```

55

```fortran
        PHR=PHR0
        IF(THETA.LE.180.) GO TO 99
        THR=(360.-THETA)*RAD
        PHR=PHR0+PI
   99 CONTINUE
c     write(6,*) 'theta,phi=',theta,phr/rad
        ET1=U0
        ET2=U0
        EP1=U0
        EP2=U0
        ETW=U0
        EPW=U0
C
C DIPOLE FIELD
C
        CALL
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,THR,P
HR,RW)
        DO 210 L=1,MT2
        ETW=ETW+RW(L)*C(L+NSURF)
  210 EPW=EPW+RW(L+MT2)*C(L+NSURF)
C
C REFLECTOR AND CAVITY FIELD CONTRIBUTIONS
C
        DO 300 M=1,MHI
        NM=M-1
        EXP1=CEXP(CMPLX(0.,FLOAT(NM)*PHR))
        EXP2=CONJG(EXP1)
        CALL
PLANES(NM,NP10,NP11,NP12,NT,RH,ZH,XT,AT,THR,RS)
        NTOP1=MODES-NM
        NTOP2=NBLOCK-(NTOP1+1)
        NS2=NTOP1*N
        NS1=NTOP2*N
        DO 250 L=1,MT1
        ET1=ET1+RS(L)*C(L+NS1)*EXP1
        EP1=EP1+RS(L+N)*C(L+NS1)*EXP1
        IF(NM.EQ.0) GO TO 250
        ET1=ET1+RS(L)*C(L+NS2)*EXP2
        EP1=EP1-RS(L+N)*C(L+NS2)*EXP2
  250 CONTINUE
        DO 260 L=1,MP1
        ET2=ET2+RS(L+MT1)*C(L+NS1+MT1)*EXP1
        EP2=EP2+RS(L+MT1+N)*C(L+NS1+MT1)*EXP1
        IF(NM.EQ.0) GO TO 260
        ET2=ET2-RS(L+MT1)*C(L+NS2+MT1)*EXP2
        EP2=EP2+RS(L+MT1+N)*C(L+NS2+MT1)*EXP2
  260 CONTINUE
  300 CONTINUE
        ET=UC*(ET1+ET2+ETW)
        EP=UC*(EP1+EP2+EPW)
        EC=ET
        EX=EP
        ECV(I)=CABS(EC)
        EXV(I)=CABS(EX)
        ECR=REAL(EC)
        ECI=AIMAG(EC)
        EXR=REAL(EX)
        EXI=AIMAG(EX)
        PHC(I)=ATAN2(ECI,ECR+1.e-10)/RAD
        PHX(I)=ATAN2(EXI,EXR+1.e-10)/RAD
        ANG(I)=THETA
        ECX=AMAX1(ECX,ECV(I),EXV(I))
  500 CONTINUE
        WRITE(8,103) PHR/RAD,ECX

  103 FORMAT(/,5X, 'PHI OF RECEIVER
(DEG)=',F8.2,/,5X,
       *'MAXIMUM FIELD VALUE (V/M)=',E15.5)
        DO 600 I=1,IT
        ECP(I)=(ECV(I)/ECX)**2
        EXP(I)=(EXV(I)/ECX)**2
        ECP(I)=AMAX1(ECP(I),.00001)
        EXP(I)=AMAX1(EXP(I),.00001)
        ECP(I)=10.*ALOG10(ECP(I))
        EXP(I)=10.*ALOG10(EXP(I))
  600 CONTINUE
        IF(IPRINT.NE.0) GO TO 310
        WRITE(8,5015)
 5015
FORMAT(///,7X,'ANGLE',15X,'CO-POL',25X,'X-POL',/,7X,
       *'(DEG)',4X,2('(VOLTS)',4X,'(DEG)',3X,'(DB-REL)',4X))
        DO 9000 L=1,IT
        WRITE(8,5016)
ANG(L),ECV(L),PHC(L),ECP(L),EXV(L),PHX(L)
       *,EXP(L)
 5016 FORMAT(5X,F6.1,3X,2(F8.4,3X,F7.1,3X,F7.2,3X))
 9000 CONTINUE
  310 CONTINUE
C
C WRITE MATLAB FILES ( .m FILES)
C
        IF(IP.EQ.1) THEN
        OPEN(2,file='ang.m')
        OPEN(3,file='cpole.m')
        OPEN(4,file='xpole.m')
        DO 9097 I=1,IT
        WRITE(2,5019) ANG(I)
        WRITE(3,5019) ECP(I)
 9097 WRITE(4,5019) EXP(I)
        CLOSE(2)
        CLOSE(3)
        CLOSE(4)
        ENDIF
        IF(IP.EQ.2) THEN
        OPEN(3,file='cpolh.m')
        OPEN(4,file='xpolh.m')
        DO 9098 I=1,IT
        WRITE(3,5019) ECP(I)
 9098 WRITE(4,5019) EXP(I)
        CLOSE(3)
        CLOSE(4)
        ENDIF
  501 CONTINUE
 5019 FORMAT(F8.3)
 9998 STOP
        END
        SUBROUTINE SOLVE(N,IPS,UL,B,X)
        COMPLEX UL(500000),B(700),X(700),SUM
        DIMENSION IPS(700)
        NP1=N+1
        IP=IPS(1)
        X(1)=B(IP)
        DO 2 I=2,N
        IP=IPS(I)
        IPB=IP
        IM1=I-1
        SUM=(0.,0.)
        DO 1 J=1,IM1
        SUM=SUM+UL(IP)*X(J)
    1 IP=IP+N
```

```
  2 X(I)=B(IPB)-SUM
    K2=N*(N-1)
    IP=IPS(N)+K2
    X(N)=X(N)/UL(IP)
    DO 4 IBACK=2,N
    I=NP1-IBACK
    K2=K2-N
    IPI=IPS(I)+K2
    IP1=I+1
    SUM=(0.,0.)
    IP=IPI
    DO 3 J=IP1,N
    IP=IP+N
  3 SUM=SUM+UL(IP)*X(J)
  4 X(I)=(X(I)-SUM)/UL(IPI)
    RETURN
    END
    SUBROUTINE DECOMP(N,IPS,UL)
    COMPLEX UL(500000),PIVOT,EM
    DIMENSION SCL(700),IPS(700)
    DO 5 I=1,N
    IPS(I)=I
    RN=0.
    J1=I
    DO 2 J=1,N
    ULM=ABS(REAL(UL(J1)))+ABS(AIMAG(UL(J1)))
    J1=J1+N
    IF(RN-ULM) 1,2,2
  1 RN=ULM
  2 CONTINUE
    SCL(I)=1./RN
  5 CONTINUE
    NM1=N-1
    K2=0
    DO 17 K=1,NM1
    BIG=0.
    DO 11 I=K,N
    IP=IPS(I)
    IPK=IP+K2

SIZE=(ABS(REAL(UL(IPK)))+ABS(AIMAG(UL(IPK))))*SCL(
IP)
    IF(SIZE-BIG) 11,11,10
 10 BIG=SIZE
    IPV=I
 11 CONTINUE
    IF(IPV-K) 14,15,14
 14 J=IPS(K)
    IPS(K)=IPS(IPV)
    IPS(IPV)=J
 15 KPP=IPS(K)+K2
    PIVOT=UL(KPP)
    KP1=K+1
    DO 16 I=KP1,N
    KP=KPP
    IP=IPS(I)+K2
    EM=-UL(IP)/PIVOT
 18 UL(IP)=-EM
    DO 16 J=KP1,N
    IP=IP+N
    KP=KP+N
    UL(IP)=UL(IP)+EM*UL(KP)
 16 CONTINUE
    K2=K2+N
 17 CONTINUE
```

```
    RETURN
    END
    FUNCTION BLOG(X)
    IF(X.GT..1) GO TO 1
    X2=X*X
    BLOG=((.075*X2-.1666667)*X2+1.)*X
    RETURN
  1 BLOG=ALOG(X+SQRT(1.+X*X))
    RETURN
    END
    SUBROUTINE ZLOAD(NP,RH,ZH,Z0,Z)
C
C COMPUTES IMPEDANCE MATRIX ELEMENTS FOR
  LOADED BODIES OF REV
C Z0(I) IS THE SURF IMPEDANCE OF THE ITH
  SEGMENT (NP-1 SEGMENTS)
C Z(.) ARE THE IMPEDANCE MATRIX TERMS
  (TRIDIAGONAL FOR T-T
C SUBMATRIX; DIAGONAL FOR P-P SUBMATRIX).
  STORED IN COL VECTOR.
C
    COMPLEX
C1,C2,Z0(400),Z(1500),X1,X2,X3,Y1,Y2,Y3,FN(400)
    COMPLEX U1,U2,U3,XI,YI
    DIMENSION RH(400),ZH(400),RS(400),D(400),SV(400)
    PI=3.14159
    MT=NP-2
    MP=NP-1
    N=MT+MP
    DO 10 IP=2,NP
    II=IP-1
    DR=RH(IP)-RH(II)
    DZ=ZH(IP)-ZH(II)
    D(II)=SQRT(DR*DR+DZ*DZ)
    SV(II)=DR/D(II)
    RS(II)=.5*(RH(IP)+RH(II))
    DS=D(II)*SV(II)/2.
    Q1=RS(II)+DS
    Q2=RS(II)-DS
    FN(II)=1.
    IF((ABS(Q2).GT.1.E-6).AND.(ABS(Q1).GT.1.E-6))
   * FN(II)=ALOG(Q1/Q2)
 10 CONTINUE
    L0=MT*3-2
    DO 20 I=1,MP
    C1=PI*Z0(I)
    IF(I.EQ.MP) GO TO 80
    KI=2
    IF(I.EQ.1) KI=1
    IF(I.EQ.MT) KI=3
    II=I+1
    C2=PI*Z0(II)
    A=SV(I)
    IF(ABS(A).LT.1.E-6) GO TO 41
    X1=C1*FN(I)/2./A
    X2=C1*2./A*(1.-RS(I)*FN(I)/D(I)/A)
    X3=-X2*RS(I)/D(I)/A
    GO TO 42
 41 CONTINUE
    X1=C1/2./RS(I)*D(I)
    X2=(0.,0.)
    X3=C1*D(I)/6./RS(I)
 42 CONTINUE
    A=SV(II)
    IF(ABS(A).LT.1.E-6) GO TO 45
```

```
      Y1=C2*FN(II)/2./A
      Y2=C2*2./A*(1.-RS(II)*FN(II)/D(II)/A)
      Y3=-Y2*RS(II)/D(II)/A
      GO TO 40
   45 CONTINUE
      Y1=C2/2./RS(II)*D(II)
      Y2=(0.,0.)
      Y3=C2*D(II)/6./RS(II)
   40 CONTINUE
C
C DEFINE TRIDIAGONAL ELEMENTS FOR T-T
SUBMATRIX (STORED IN COLS)
C (U1- DIAG; U2- LOWER; U3- UPPER)
C
      XI=X1+X2+X3
      YI=Y1-Y2+Y3
      IF(KI.EQ.1) XI=C1/SV(I)
C   IF(KI.EQ.3) YI=C2/SV(II)
      U1=XI+YI
      U2=X1-X3
      U3=Y1-Y3
      L=2+(I-2)*3
      IF(KI.EQ.1) L=0
      L1=L+1
      L2=L+2
      L3=L+3
      go to (50,60,70),ki
   50 Z(L1)=U1
      Z(L2)=U2
      GO TO 80
   60 Z(L1)=U3
      Z(L2)=U1
      Z(L3)=U2
      GO TO 80
   70 Z(L1)=U3
      Z(L2)=U1
   80 Z(L0+I)=2.*C1*D(I)/RS(I)
   20 CONTINUE
      RETURN
      END
      SUBROUTINE ZTOT(MT,MP,ZL,Z)
C
C ADDS THE SURF IMPEDANCE TERMS TO THE
TRIDIAGONAL ELEMENTS OF
C THE BOR IMPEDANCE MATRIX Z.
C
      COMPLEX ZL(700),Z(50000)
      N=MT+MP
      M0=MT*3-2
      DO 100 I=1,MP
      L0=MT*N+(I-1)*N+MT
      IF(I.EQ.MP) GO TO 80
      KI=2
      IF(I.EQ.1) KI=1
      IF(I.EQ.MT) KI=3
      L2=(I-1)*N+I
      L1=L2-1
      L3=L2+1
      M=2+3*(I-2)
      IF(KI.EQ.1) M=0
      M1=M+1
      M2=M+2
      M3=M+3
      go to (50,60,70),ki
   50 Z(L2)=Z(L2)+ZL(M1)
```

```
      Z(L3)=Z(L3)+ZL(M2)
      GO TO 80
   60 Z(L1)=Z(L1)+ZL(M1)
      Z(L2)=Z(L2)+ZL(M2)
      Z(L3)=Z(L3)+ZL(M3)
      GO TO 80
   70 Z(L1)=Z(L1)+ZL(M1)
      Z(L2)=Z(L2)+ZL(M2)
   80 Z(L0+I)=Z(L0+I)+ZL(M0+I)
  100 CONTINUE
      RETURN
      END
      subroutine interp(u,v,x,y,nn)
c program to interpolate linearly between arrays of x and y
c values (with dimensions nn).  u is specified and v is
returned
c uniform sampling in x (the ordinate) is assumed.
      dimension x(nn),y(nn)
      delx=x(2)-x(1)
      n1=int(u/delx)+1
      n2=n1+1
      dely=y(n2)-y(n1)
      sgn=sign(1.,dely)
      dely=abs(dely)
      alpha=u-x(n1)
      zeta=dely*alpha/delx
      v=y(n1)+sgn*zeta
      return
      end
      SUBROUTINE
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,
     * THR,PHR,R)
C
C  PLANE WAVE EXCITATION VECTOR ELEMENTS FOR
WIRE AND
C  ATTACHMENT SEGMENT. INCIDENCE DIRECTION IS
(THR,PHR).
C   - ONLY ONE INCIDENCE ANGLE PER CALL
C   - WIRE DOES NOT HAVE TO LIE IN THE Z=0 PLANE
C
      COMPLEX
U0,AA,BB,C,R(400),CEXP,EXP,FI1,FI2,SI,DI,CMPLX
      DIMENSION
ZH(400),NS(4),NW1(4),NW2(4),XH(400),YH(400)
      MP2=NP2-1
      MT2=NP2-2
      MT22=2*MT2
      DO 5 L=1,NWIRES
    5 NS(L)=NW2(L)-NW1(L)+1
      U0=(0.,0.)
      CC=COS(THR)
      SS=SIN(THR)
      CP=COS(PHR)
      SP=SIN(PHR)
      UP=SS*CP
      VP=SS*SP
      WP=CC
      DO 12 IP=1,MP2
      II=IP+NP1
      I=II+1
      ZS=.5*(ZH(I)+ZH(II))
      XS=.5*(XH(I)+XH(II))
      YS=.5*(YH(I)+YH(II))
      DX=XH(I)-XH(II)
      DY=YH(I)-YH(II)
```

```fortran
      D1=SQRT(DX**2+DY**2)
      SU=DY/D1
      CU=DX/D1
C FOR WIRES IN PERPENDICULAR TO Z SIN(V)=1 AND
COS(V)=0
      SV=1.0
      CV=0.0
C
C WIRE SEGMENT CALCULATIONS
C
      A=UP*CU+VP*SU
      B=UP*XS+VP*YS+WP*ZS
      C=CMPLX(0.,A)
      EXP=CEXP(CMPLX(0.,3))
      AA=CC*(CU*CP+SU*SP)
      BB=SU*CP-SP*CU
      PSI=D1*A/2.
      IF(PSI.NE.0.) GO TO 60
      SINC=1.
      GO TO 61
   60 SINC=SIN(PSI)/PSI
   61 COSP=COS(PSI)
      FI1=SINC*D1*EXP/2.
      FI2=(0.,0.)
      IF(ABS(A).LT.1.E-4) GO TO 62
      CSP=COSP-SINC
      IF(ABS(CSP).LT.1.E-4) GO TO 62
      FI2=EXP/C*CSP
   62 CONTINUE
      SI=FI1+FI2
      DI=FI1-FI2
C
C R-WIRE-THETA
C
      IF(IP.EQ.MP2) GO TO 10
      R(IP)=AA*SI
      R(IP+MT2)=BB*SI
   10 CONTINUE
C
C R-WIRE-PHI
C
   14 IF(IP.EQ.1) GO TO 12
      R(IP-1)=R(IP-1)+AA*DI
      R(IP-1+MT2)=R(IP-1+MT2)+BB*DI
   12 CONTINUE
C
C WRITE OVER DUMMY WIRE SEGMENTS
C
c     IF(NWIRES.EQ.1) GO TO 210
c     NSPTS=0
c     DO 209 L=1,NWIRES-1
c     NSPTS=NSPTS+NS(L)
c     IN=NSPTS-2
c     R(IN+1)=U0
c     R(IN+2)=U0
c     IN=IN+MT2
c     R(IN+1)=U0
c     R(IN+2)=U0
c 209 CONTINUE
  210 RETURN
      END
      SUBROUTINE
PLANES(M1,NP0,NP1,NP2,NT,RH,ZH,XT,AT,THR,R)
C

C PLANE WAVE EXCITATION VECTOR FOR BOR
ELEMENTS.
C NO CHANGE FROM HARRINGTON'S ORIGINAL
PROGRAM OTHER THAN
C
C ** ONLY ONE MODE PER CALL **
C
      COMPLEX
R(1000),U,U1,UA,UB,FA(50),FB(50),F2A,F2B,F1A,F1B
      COMPLEX U2,U3,U4,U5,CMPLX
      DIMENSION RH(400),ZH(400),XT(4),AT(4)
      DIMENSION R2(4),Z2(4),BJ(5000)
      U=(0.,1.)
      U1=3.141593*U**M1
      NF=1
      M2=M1
      NP=NP0+NP1+NP2
      NRF=NP0+NP1
      MP=NP-1
      MT=MP-1
      N=MT+MP
      N2=2*N
      CC=COS(THR)
      SS=SIN(THR)
      M3=M1+1
      M4=M2+3
      IF(M1.EQ.0) M3=2
      M5=M1+2
      M6=M2+2
      DO 12 IP=1,MP
      K2=IP
      I=IP+1
      DR=.5*(RH(I)-RH(IP))
      DZ=.5*(ZH(I)-ZH(IP))
      D1=SQRT(DR*DR+DZ*DZ)
      R1=.25*(RH(I)+RH(IP))
      IF(ABS(R1).LT.1.E-5) R1=1.
      Z1=.5*(ZH(I)+ZH(IP))
      DR=.5*DR
      D2=DR/R1
      DO 13 L=1,NT
      R2(L)=R1+DR*XT(L)
      Z2(L)=Z1+DZ*XT(L)
   13 CONTINUE
      D3=DR*CC
      D4=-DZ*SS
      D5=D1*CC
      DO 23 M=M3,M4
      FA(M)=0.
      FB(M)=0.
   23 CONTINUE
      DO 15 L=1,NT
      X=SS*R2(L)
      IF(X.GT..5E-7) GO TO 19
      DO 20 M=M3,M4
      BJ(M)=0.
   20 CONTINUE
      BJ(2)=1.
      S=1.
      GO TO 18
   19 M=2.8*X+14.-2./X
      IF(X.LT..5) M=11.8+ALOG10(X)
      IF(M.LT.M4) M=M4
      BJ(M)=0.
      JM=M-1
```

```
      BJ(JM)=1.
      DO 16 J=4,M
      J2=JM
      JM=JM-1
      J1=JM-1
      BJ(JM)=J1/X*BJ(J2)-BJ(JM+2)
   16 CONTINUE
      S=0.
      IF(M.LE.4) GO TO 24
      DO 17 J=4,M,2
      S=S+BJ(J)
   17 CONTINUE
   24 S=BJ(2)+2.*S
   18 ARG=Z2(L)*CC
      UA=AT(L)/S*CMPLX(COS(ARG),SIN(ARG))
      UB=XT(L)*UA
      DO 25 M=M3,M4
      FA(M)=BJ(M)*UA+FA(M)
      FB(M)=BJ(M)*UB+FB(M)
   25 CONTINUE
   15 CONTINUE
      IF(M1.NE.0) GO TO 26
      FA(1)=- FA(3)
      FB(1)=- FB(3)
   26 UA=U1
      DO 27 M=M5,M6
      M7=M-1
      M8=M+1
      F2A=UA*(FA(M8)+FA(M7))
      F2B=UA*(FB(M8)+FB(M7))
      UB=U*UA
      F1A=UB*(FA(M8)-FA(M7))
      F1B=UB*(FB(M8)-FB(M7))
      U4=D4*UA
      U2=D3*F1A+U4*FA(M)
      U3=D3*F1B+U4*FB(M)
      U4=DR*F2A
      U5=DR*F2B
      K1=K2-1
      K4=K1+N
      K5=K2+N
      R(K2+MT)=-D5*(F2A+D2*F2B)
      R(K5+MT)=D1*(F1A+D2*F1B)
      IF(IP.EQ.1) GO TO 21
      R(K1)=R(K1)+U2-U3
      R(K4)=R(K4)+U4-U5
      IF(IP.EQ.MP) GO TO 22
   21 R(K2)=U2+U3
      R(K5)=U4+U5
   22 K2=K2+N2
      UA=UB
   27 CONTINUE
   12 CONTINUE
c     R(NP0-1)=(0.,0.)
c     R(NP0)=(0.,0.)
c     R(NP0+MT)=(0.,0.)
c     R(NRF-1)=(0.,0.)
c     R(NRF)=(0.,0.)
c     R(NRF+MT)=(0.,0.)
   99 RETURN
      END
      SUBROUTINE
      ZMATSS(M1,M2,NP0,NP1,NP2,NPHI,NT,RH,ZH,X,A,XT,A
      T,Z)
      C
```

```
C ******** THREE DETACHED SURFACES **********
C SURFACE-SURFACE IMPEDANCE ELEMENTS
      REMAINS UNCHANGED FROM HARRINGTON
C EXCEPT MULTIPLE SURFACES ARE PERMITTED.
      THE FIRST SURFACE HAS NP0
C POINTS. THE SECOND NP1 POINTS AND THE THIRD
      NP2.
C NP0 PARABOLOID PTS; NP1 HYPERBOLOID PTS,
      NP2 CAVITY PTS.
      C
      COMPLEX
      Z(50000),U1,U2,U3,U4,U5,U6,U7,U8,U9,UA,UB,G4A(4),G5
      A(4)
      COMPLEX
      G6A(4),G4B(4),G5B(4),G6B(4),H4A,H5A,H6A,H4B,H5B
      COMPLEX CMPLX,H6B,UC,UD,GA(400),GB(400)
      DIMENSION
      RH(400),ZH(400),X(400),A(400),AT(4),RS(400),ZS(400)
      DIMENSION
      D(400),DR(400),DZ(400),DM(400),C2(400),C3(400),R2(4)
      DIMENSION
      C4(400),C5(400),C6(400),Z7(4),R7(4),Z8(4),R8(4)
      DIMENSION XT(4),Z2(4)
      CT=2.
      CP=.1
      NP=NP0+NP1+NP2
      NRF=NP0+NP1
      DO 10 I=2,NP
      I2=I-1
      RS(I2)=.5*(RH(I)+RH(I2))
      ZS(I2)=.5*(ZH(I)+ZH(I2))
      D1=.5*(RH(I)-RH(I2))
      D2=.5*(ZH(I)-ZH(I2))
      D(I2)=SQRT(D1*D1+D2*D2)
      DR(I2)=D1
      DZ(I2)=D2
      DM(I2)=D(I2)/RS(I2)
   10 CONTINUE
      M3=M2-M1+1
      M4=M1-1
      PI2=1.570796
      DO 11 K=1,NPHI
      PH=PI2*(X(K)+1.)
      C2(K)=PH*PH
      SN=SIN(.5*PH)
      C3(K)=4.*SN*SN
      A1=PI2*A(K)
      D4=.5*A1*C3(K)
      D5=A1*COS(PH)
      D6=A1*SIN(PH)
      M5=K
      DO 29 M=1,M3
      PHM=(M4+M)*PH
      A2=COS(PHM)
      C4(M5)=D4*A2
      C5(M5)=D5*A2
      C6(M5)=D6*SIN(PHM)
      M5=M5+NPHI
   29 CONTINUE
   11 CONTINUE
      MP=NP-1
      MT=MP-1
      N=MT+MP
      N2N=MT*N
      N2=N*N
```

```
U1=(0.,5.)                              SN=-SIN(R)
U2=(0.,2.)                              CS=COS(R)
JN=-1-N                                 UC=AT(L)/R*CMPLX(CS,SN)
DO 15 JQ=1,MP                           UA=UA+UC
KQ=2                                    UB=XT(L)*UC+UB
IF(JQ.EQ.1) KQ=1                     35 CONTINUE
IF(JQ.EQ.MP) KQ=3                       GO TO 36
R1=RS(JQ)                            34 DO 37 L=1,NT
Z1=ZS(JQ)                               R=SQRT(Z8(L)+R8(L)*A1)
D1=D(JQ)                                SN=-SIN(R)
D2=DR(JQ)                               CS=COS(R)
D3=DZ(JQ)                               UC=AT(L)/R*SN*CMPLX(-SN,CS)
D4=D2/R1                                UA=UA+UC
D5=DM(JQ)                               UB=XT(L)*UC+UB
SV=D2/D1                             37 CONTINUE
CV=D3/D1                                A2=FM+R5*A1
T6=CT*D1                                D9=RR-A2*A2
T62=T6+D1                               R=ABS(A2)
T62=T62*T62                             D7=R-D1
R6=CP*R1                                D8=R+D1
R62=R6*R6                               D6=SQRT(D8*D8+D9)
DO 12 L=1,NT                            R=SQRT(D7*D7+D9)
R2(L)=R1+D2*XT(L)                       IF(D7.GE.0.) GO TO 38
Z2(L)=Z1+D3*XT(L)                       A1=ALOG((D8+D6)*(-D7+R)/D9)/D1
12 CONTINUE                             GO TO 39
U3=D2*U1                             38 A1=ALOG((D8+D6)/(D7+R))/D1
U4=D3*U1                             39 UA=A1+UA
DO 16 IP=1,MP                           UB=A2*(4./(D6+R)-A1)/D1+UB
R3=RS(IP)                            36 GA(K)=UA
Z3=ZS(IP)                               GB(K)=UB
R4=R1-R3                             33 CONTINUE
Z4=Z1-Z3                                K1=0
FM=R4*SV+Z4*CV                          DO 45 M=1,M3
PHM=ABS(FM)                             H4A=0.
PH=ABS(R4*CV-Z4*SV)                     H5A=0.
D6=PH                                   H6A=0.
IF(PHM.LE.D1) GO TO 26                  H4B=0.
D6=PHM-D1                               H5B=0.
D6=SQRT(D6*D6+PH*PH)                    H6B=0.
26 IF(IP.EQ.JQ) GO TO 27                DO 46 K=1,NPHI
KP=1                                    K1=K1+1
IF(T6.GT.D6) KP=2                       D6=C4(K1)
IF(R6.GT.D6) KP=3                       D7=C5(K1)
GO TO 28                                D8=C6(K1)
27 KP=4                                 UA=GA(K)
28 GO TO (41,42,41,42),KP               UB=GB(K)
42 DO 40 L=1,NT                         H4A=D6*UA+H4A
D7=R2(L)-R3                             H5A=D7*UA+H5A
D8=Z2(L)-Z3                             H6A=D8*UA+H6A
Z7(L)=D7*D7+D8*D8                       H4B=D6*UB+H4B
R7(L)=R3*R2(L)                         H5B=D7*UB+H5B
Z8(L)=.25*Z7(L)                        H6B=D8*UB+H6B
R8(L)=.25*R7(L)                     46 CONTINUE
40 CONTINUE                             G4A(M)=H4A
Z4=R4*R4+Z4*Z4                          G5A(M)=H5A
R4=R3*R1                                G6A(M)=H6A
R5=.5*R3*SV                             G4B(M)=H4B
DO 33 K=1,NPHI                          G5B(M)=H5B
A1=C3(K)                                G6B(M)=H6B
RR=Z4+R4*A1                          45 CONTINUE
UA=0.                                   IF(KP.NE.4) GO TO 47
UB=0.                                   A2=D1/(PI2*R1)
IF(RR.LT.T62) GO TO 34                  D6=2./D1
DO 35 L=1,NT                            D8=0.
R=SQRT(Z7(L)+R7(L)*A1)                  DO 63 K=1,NPHI
```

61

```
A1=R4*C2(K)                                    G5B(M)=A2*U6+G5B(M)
R=R4*C3(K)                                     G6B(M)=A2*U7+G6B(M)
IF(R.LT.T62) GO TO 64                       30 CONTINUE
D7=0.                                       13 CONTINUE
DO 65 L=1,NT                                 47 A1=DR(IP)
D7=D7+AT(L)/SQRT(Z7(L)+A1)                      UA=A1*U3
65 CONTINUE                                     UB=DZ(IP)*U4
GO TO 66                                        A2=D(IP)
64 A1=A2/(X(K)+1.)                              D6=-A2*D2
D7=D6*ALOG(A1+SQRT(1.+A1*A1))                   D7=D1*A1
66 D8=D8+A(K)*D7                                D8=D1*A2
63 CONTINUE                                      JM=JN
A1=.5*A2                                         DO 31 M=1,M3
A2=1./A1                                         FM=M4+M
D8=-PI2*D8+2./R1*(BLOG(A2)+A2*BLOG(A1))          A1=FM*DM(IP)
DO 67 M=1,M3                                     H5A=G5A(M)
G5A(M)=D8+G5A(M)                                 H5B=G5B(M)
67 CONTINUE                                      H4A=G4A(M)+H5A
GO TO 47                                         H4B=G4B(M)+H5B
41 DO 25 M=1,M3                                  H6A=G6A(M)
G4A(M)=0.                                        H6B=G6B(M)
G5A(M)=0.                                        U7=UA*H5A+UB*H4A
G6A(M)=0.                                        U8=UA*H5B+UB*H4B
G4B(M)=0.                                        U5=U7-U8
G5B(M)=0.                                        U6=U7+U8
G6B(M)=0.                                        U7=-U1*H4A
25 CONTINUE                                      U8=D6*H6A
DO 13 L=1,NT                                     U9=D6*H6B-A1*H4A
A1=R2(L)                                         UC=D7*(H6A+D4*H6B)
R4=A1-R3                                         UD=FM*D5*H4A
Z4=Z2(L)-Z3                                      K1=IP+JM
Z4=R4*R4+Z4*Z4                                   K2=K1+1
R4=R3*A1                                         K3=K1+N
DO 17 K=1,NPHI                                   K4=K2+N
R=SQRT(Z4+R4*C3(K))                             K5=K2+MT
SN=-SIN(R)                                      K6=K4+MT
CS=COS(R)                                       K7=K3+N2N
GA(K)=CMPLX(CS,SN)/R                            K8=K4+N2N
17 CONTINUE                                      GO TO (18,20,19),KQ
D6=0.                                        18 Z(K6)=U8+U9
IF(R62.LE.Z4) GO TO 51                          IF(IP.EQ.1) GO TO 21
DO 62 K=1,NPHI                                  Z(K3)=Z(K3)+U6-U7
D6=D6+A(K)/SQRT(Z4+R4*C2(K))                    Z(K7)=Z(K7)+UC-UD
62 CONTINUE                                      IF(IP.EQ.MP) GO TO 22
Z4=3.141593/SQRT(Z4/R4)                      21 Z(K4)=U6+U7
D6=-PI2*D6+ALOG(Z4+SQRT(1.+Z4*Z4))/SQRT(R4)     Z(K8)=UC+UD
51 A1=AT(L)                                      GO TO 22
A2=XT(L)*A1                                  19 Z(K5)=Z(K5)+U8-U9
K1=0                                            IF(IP.EQ.1) GO TO 23
DO 30 M=1,M3                                    Z(K1)=Z(K1)+U5+U7
U5=0.                                           Z(K7)=Z(K7)+UC-UD
U6=0.                                           IF(IP.EQ.MP) GO TO 22
U7=0.                                        23 Z(K2)=Z(K2)+U5-U7
DO 32 K=1,NPHI                                  Z(K8)=UC+UD
UA=GA(K)                                         GO TO 22
K1=K1+1                                      20 Z(K5)=Z(K5)+U8-U9
U5=C4(K1)*UA+U5                                 Z(K6)=U8+U9
U6=C5(K1)*UA+U6                                 IF(IP.EQ.1) GO TO 24
U7=C6(K1)*UA+U7                                 Z(K1)=Z(K1)+U5+U7
32 CONTINUE                                      Z(K3)=Z(K3)+U6-U7
U6=D6+U6                                         Z(K7)=Z(K7)+UC-UD
G4A(M)=A1*U5+G4A(M)                             IF(IP.EQ.MP) GO TO 22
G5A(M)=A1*U6+G5A(M)                          24 Z(K2)=Z(K2)+U5-U7
G6A(M)=A1*U7+G6A(M)                             Z(K4)=U6+U7
G4B(M)=A2*U5+G4B(M)                             Z(K8)=UC+UD
```

62

```
    22 Z(K8+MT)=U2*(D8*(H5A+D4*H5B)-A1*UD)
       JM=JM+N2
    31 CONTINUE
    16 CONTINUE
       JN=JN+N
    15 CONTINUE
 C
 C THREE MULTIPLE BODIES USING THE SIMPLIFIED
 APPROACH
 C NULL OUT ROWS AND COLS FOR THE FIRST
 DUMMY SEGMENT
 C
       DO 100 LSS=1,N
       LS=LSS-1
       Z(LS*N+NP0)=(0..0.)
       Z(LS*N+NP0-1)=(0..0.)
   100 Z(LS*N+NP0+MT)=(0.,0.)
       DO 101 LS=1,N
       Z((NP0-2)*N+LS)=(0..0.)
       Z((NP0-1)*N+LS)=(0..0.)
   101 Z((NP0-1+MT)*N+LS)=(0..0.)
       Z((NP0-2)*N+NP0-1)=(1..0.)
       Z((NP0-1)*N+NP0)=(1..0.)
       Z((MT+NP0-1)*N+NP0+MT)=(1..0.)
 C
 C NULL OUT ROWS AND COLS FOR THE SECOND
 DUMMY SEGMENT
 C
       DO 200 LSS=1,N
       LS=LSS-1
       Z(LS*N+NRF)=(0..0.)
       Z(LS*N+NRF-1)=(0..0.)
   200 Z(LS*N+NRF+MT)=(0..0.)
       DO 201 LS=1,N
       Z((NRF-2)*N+LS)=(0..0.)
       Z((NRF-1)*N+LS)=(0..0.)
   201 Z((NRF-1+MT)*N+LS)=(0..0.)
       Z((NRF-2)*N+NRF-1)=(1..0.)
       Z((NRF-1)*N+NRF)=(1..0.)
       Z((MT+NRF-1)*N+NRF+MT)=(1..0.)
   999 RETURN
       END
       SUBROUTINE ZASMB0(NP1.NP2.MODES.Z.ZWW)
 C
 C ASSEMBLES MODE INDEPENDENT BLOCKS OF Z
 C
       COMPLEX Z(500000).ZWW(10000)
       MT1=NP1-2
       MP1=NP1-1
       N=MT1+MP1
       MT2=NP2-2
       NBLOCK=2*MODES+1
       NS=NBLOCK*N
       NR=NS+MT2
       NS2=NS*NR
       NWW=NS2+NS
       DO 10 IC=1,MT2
       IC1=IC-1
       DO 10 IR=1,MT2
       K=NWW+IC1*NR+IR
       IW=IC1*MT2+IR
    10 Z(K)=ZWW(IW)
       RETURN
       END
```

```
       SUBROUTINE
 ZASMBN(NP1.NP2.MODES.NM.Z.ZSS.ZSW)
 C
 C ASSEMBLES MODE DEPENDENT BLOCKS IN Z.
 MODES=TL # OF MODES;
 C NM IS THE MODE # OF THE BLOCKS ZSS.ZSW.ZSJ.
 (IF NM<0 THEN
 C ZSS IS OMITTED - ONLY FILLED FOR POSITIVE NM)
 C
       COMPLEX ZSS(50000).Z(500000).ZSW(50000)
       MT1=NP1-2
       MP1=NP1-1
       MT2=NP2-2
       N=MP1+MT1
       NBLOCK=2*MODES+1
       NS=NBLOCK*N
       NR=NS+MT2
       MT=MT1+MT2
       MTN=MT*N
       IF(NM.LT.0) GO TO 225
 C
 C ZSS BLOCKS FOR MODE NM (+ AND - FILLED IN 1
 LOOP)
 C
       NTOP1=MODES-NM
       NTOP2=NBLOCK-(NTOP1+1)
       NSS2=NTOP1*(N+NR*N)
       NSS1=NTOP2*(N+NR*N)
       DO 200 IC=1,MP1
       IC1=IC-1
       DO 200 IR=1,MP1
       IF(IC.GT.MT1) GO TO 100
       IF(IR.GT.MT1) GO TO 50
       I0=IC1*N+IR
       ITT='C .*NR+IR
       Z(I' .+NSS1)=ZSS(I0)
       IF(NM.NE.0) Z(ITT+NSS2)=ZSS(I0)
    50 I0=MT1+IC1*N+IR
       IPT=IC1*NR+MT1+IR
       Z(IPT+NSS1)= ZSS(I0)
       IF(NM.NE.0) Z(IPT+NSS2)=-ZSS(I0)
   100 IF(IR.GT.MT1) GO TO 150
       I0=N*MT1+IC1*N+IR
       ITP=MT1*NR+IC1*NR+IR
       Z(ITP+NSS1)= ZSS(I0)
       IF(NM.NE.0) Z(ITP+NSS2)=-ZSS(I0)
   150 I0=N*MT1+MT1+IC1*N+IR
       IPP=IC1*NR+MT1+MT1*NR+IR
       Z(IPP+NSS1)=ZSS(I0)
       IF(NM.NE.0) Z(IPP+NSS2)=ZSS(I0)
   200 CONTINUE
   225 CONTINUE
 C
 C ZSW AND ZWS BLOCKS
 C
       NTOP1=MODES+NM
       NTOP2=NBLOCK-(NTOP1+1)
       NSW=NTOP1*N+NS*NR
       NWS=NTOP2*NR*N+NS
       DO 250 IC=1,MT2
       IC1=IC-1
       DO 250 IR=1,N
       ISW=IR+IC1*NR+NSW
       IWS=(IR-1)*NR+IC+NWS
       I0=IC1*N+IR
```

```
      Z(ISW)=ZSW(I0)                          RS1(N0)=.5*(RH(I)+RH(I2))
      Z(IWS)=ZSW(I0)                          ZS1(N0)=.5*(ZH(I)+ZH(I2))
250   CONTINUE                                XS1(N0)=.5*(XH(I)+XH(I2))
      RETURN                                  YS1(N0)=.5*(YH(I)+YH(I2))
      END                                     DX=XH(I)-XH(I2)
      SUBROUTINE                              DY=YH(I)-YH(I2)
ZMATSW(NWIRES,NW1,NW2,NP11,NP12,NP13,         D1(N0)=SQRT(DX**2+DY**2)
     * XH,YH,RH,ZH,NT,XT,AT,NG,XG,AG,MODE,A,Z) C FOR WIRES PARALLEL TO THE XY PLANE SIN(V)=1
C                                          AND COS(V)=0
c >>>>>>>>>>> revised version <<<<<<<<<<         S1(N0)=1.
c                                               C1(N0)=0.
C CALCULATION OF THE SURFACE-WIRE MATRIX         CU(N0)=DX/D1(N0)
ELEMENTS. ATTACHMENT                            SU(N0)=DY/D1(N0)
C POINT NOT AT A SURFACE EDGE, BUT CAN BE ON Z 10 CONTINUE
AXIS (IC#1). SURFACE                            CON=U/PI2/2.
C START INDEX IS 1. TWO BORS OF LENGTHS NP11, C INTEGRATING FROM 0 TO 2*PI
NP12 AND NP13. WIRE                             O1=PI
C START AND STOP POINTS ARE NW1 AND NW2.        O2=PI
C                                               JN=-1-NROW
      COMPLEX                                 C
CEXP,EXP,Z(50000),G5,G6,G7,CONH,F5,F6,F7       C SEGMENT LOOPS: q=WIRE, p=SURFACE
      COMPLEX                                 C
U,U0,PSI,T0,T1,T2,T3,ST1,ST2,ST3,CON,SP1,SP2,SP3     DO 100 JQ=1,NW
      COMPLEX U5,U6,U7,U8,U9,CMPLX,T4,T5,T6,T7       KQ=2
      DIMENSION                                   IF(JQ.EQ.1) KQ=1
RS1(400),RH(400),ZH(400),XG(400),AG(400),XT(4),AT(4)   IF(JQ.EQ.NW) KQ=3
      DIMENSION                                   H1=D1(JQ)/2.
ZS1(400),D1(400),D(400),S(400),C(400),RS(400)       ZW=ZS1(JQ)
      DIMENSION                                   DO 22 IP=1,MP
ZS(400),S1(400),C1(400),NW1(4),NW2(4),NS(4)         ST1=U0
      DIMENSION                                   ST2=U0
XH(400),YH(400),XS1(400),YS1(400),CU(400),SU(400)   ST3=U0
      PI=3.14159                                  SP1=U0
      PI2=2.*PI                                   SP2=U0
      NP1=NP11+NP12+NP13                          SP3=U0
      NRF=NP11+NP12                               AA=S(IP)*CU(JQ)
      DO 1 L=1,NWIRES                             BB=S(IP)*SU(JQ)
    1 NS(L)=NW2(L)-NW1(L)+1                       RD=RS(IP)*D1(JQ)
      U0=(0.,0.)                                  DD=D(IP)*D1(JQ)
      U=(0.,1.)                                   CONH=CON*D(IP)
C                                          C
C DEFINE SURFACE GEOMETRY TERMS            C FIRST TERM (H-INTEGRATION)
C                                          C
      MP=NP1-1                                    DO 30 I=1,NT
      MT=MP-1                                      H=H1*XT(I)
      NROW=MP+MT                                   HHD=2.*H/D1(JQ)
      DO 5 I=2,NP1                                 XW=XS1(JQ)+H*CU(JQ)
      I2=I-1                                        YW=YS1(JQ)+H*SU(JQ)
      RS(I2)=.5*(RH(I)+RH(I2))               C
      ZS(I2)=.5*(ZH(I)+ZH(I2))               C PHI INTEGRATIONS FOR G-HAT FUNCTIONS
      DR=RH(I)-RH(I2)                         C
      DZ=ZH(I)-ZH(I2)                              G7=U0
      D(I2)=SQRT(DR**2+DZ**2)                      G5=U0
      S(I2)=DR/D(I2)                               G6=U0
    5 C(I2)=DZ/D(I2)                               DO 32 K=1,NG
C                                                  PH=O1*XG(K)+O2
C DEFINE WIRE GEOMETRY TERMS                       PHM=PH*FLOAT(MODE)
C                                                  XS=RS(IP)*COS(PH)
      NW=NW2(NWIRES)-NW1(1)                        YS=RS(IP)*SIN(PH)
      NWP=NW+1                                      EXP=CEXP(CMPLX(0.,-PHM))
      MT2=NWP-2                                     RP=SQRT((XS-XW)**2+(YS-YW)**2+(ZS(IP)-ZW)**2)
      DO 10 N=2,NWP                                 PSI=CEXP(CMPLX(0.,-RP))/RP
      N0=N-1                                        F5=EXP*COS(PH)*PSI
      I=NP1+N                                       F6=EXP*SIN(PH)*PSI
      I2=I-1                                        F7=EXP*PSI
```

64

```
      G7=G7+F7*AG(K)
      G5=G5+F5*AG(K)
   32 G6=G6+F6*AG(K)
      G7=O1*G7
      G5=O1*G5
      G6=O1*G6
      T0=G5*AA/4.
      T1=T0*HHD
      T2=G6*BB/4.
      T3=T2*HHD
      T4=G5*SU(JQ)/2.
      T5=T4*HHD
      T6=-G6*CU(JQ)/2.
      T7=T6*HHD
      ST1=ST1+AT(I)*(T0+T2)
      ST2=ST2+AT(I)*(T1+T3)
      ST3=ST3+AT(I)*G7/DD
      SP1=SP1+AT(I)*(T4+T6)
      SP2=SP2+AT(I)*(T5+T7)
      SP3=SP3+AT(I)*U*G7*FLOAT(MODE)/RD
   30 CONTINUE
C
C ZSW-t TERMS (K1,K2,K3,K4)
C
      U5=(ST1-ST2)*CONH*H1
      U6=(ST1+ST2)*CONH*H1
      U7=-ST3*CONH*H1
C
C ZSW-p TERMS (K5,K6)
C
      U8=SP1*CONH*H1
      U9=(SP2+SP3)*CONH*H1
      K1=IP+JN
      K2=K1+1
      K3=K1+NROW
      K4=K2+NROW
      K5=K2+MT
      K6=K4+MT
      GO TO (18,20,19),KQ
   18 Z(K6)=U8+U9
      IF(IP.EQ.1) GO TO 21
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.MP) GO TO 22
   21 Z(K4)=U6+U7
      GO TO 22
   19 Z(K5)=Z(K5)+U8-U9
      IF(IP.EQ.1) GO TO 23
      Z(K1)=Z(K1)+U5+U7
      IF(IP.EQ.MP) GO TO 22
   23 Z(K2)=Z(K2)+U5-U7
      GO TO 22
   20 Z(K5)=Z(K5)+U8-U9
      Z(K6)=U8+U9
      IF(IP.EQ.1) GO TO 24
      Z(K1)=Z(K1)+U5+U7
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.MP) GO TO 22
   24 Z(K2)=Z(K2)+U5-U7
      Z(K4)=U6+U7
   22 CONTINUE
      JN=JN+NROW
  100 CONTINUE
C
C FOR MULTIPLE BORS WRITE OVER DUMMY
SEGMENT ROWS
```

```
C WRITE OVER ROWS AND COLS FOR FIRST DUMMY
SEG.
C
      DO 101 LSS=1,MT2
      LS=LSS-1
      Z(LS*NROW+NP11)=(0.,0.)
      Z(LS*NROW+NP11-1)=(0.,0.)
  101 Z(LS*NROW+NP11+MT)=(0.,0.)
C
C WRITE OVER ROWS AND COLS FOR SECOND
DUMMY SEG.
C
      DO 201 LSS=1,MT2
      LS=LSS-1
      Z(LS*NROW+NRF)=(0.,0.)
      Z(LS*NROW+NRF-1)=(0.,0.)
  201 Z(LS*NROW+NRF+MT)=(0.,0.)
C
C WRITE OVER DUMMY SEGMENTS IN THE CASE OF
MULTIPE WIRES
C
      IF(NWIRES.EQ.1) GO TO 292
      NSPTS=0
      DO 291 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      DO 291 I=1,NROW
C
C SET COLS TO ZERO FOR STRIPS
C
      IN=(NSPTS-2)*NROW
      Z(IN+I)=U0
      Z(IN+I+NROW)=U0
  291 CONTINUE
  292 RETURN
      END
      SUBROUTINE
ZMATWW(NWIRES,NW1,NW2,XH,YH,RH,ZH,NT,XT,AT,A,
Z)
C
C *** MODS FOR DIPOLE -- RECTANGULAR
COORDINATES ARE SENT OVER ***
C COMPUTE MATRIX ELEMENTS FOR MULTIPLE
WIRES USING GLISSON METHOD
C NWIRES= # OF WIRES; NW1(I),NW2(I) ARE START
AND STOP POINTS.
C &&&&& WIRES NEED NOT BE IN THE Z=0 PLANE
&&&&&
C
      COMPLEX CEXP,Z(10000),CON,CMPLX
      COMPLEX U,U0,PSI,SUM1,SUM2,SUM3,U5,U6,U7
      DIMENSION
RH(400),ZH(400),XT(4),AT(4),XH(400),YH(400)
      DIMENSION D1(400),S1(400),C1(400)
      DIMENSION
NW1(4),NW2(4),NS(4),XS1(400),YS1(400),ZS1(400)
      DIMENSION CU(400),SU(400)
      PI=3.141592
      PI2=2.*PI
      PD2=PI/2.
      U0=(0.,0.)
      U=(0.,1.)
C
C DEFINE GEOMETRY TERMS FOR THE WIRE.
XH,YH,RH,ZH ARE ALL KNOWNS.
C
```

```
      DO 5 L=1,NWIRES
    5 NS(L)=NW2(L)-NW1(L)+1
      NS1=NW2(NWIRES)-NW1(1)
      NPS=NS1+1
      DO 10 N=2,NPS
      N0=N-1
      I=NW1(1)+N-1
      I2=I-1
      XS1(N0)=.5*(XH(I)+XH(I2))
      YS1(N0)=.5*(YH(I)+YH(I2))
      ZS1(N0)=.5*(ZH(I)+ZH(I2))
      DX=XH(I)-XH(I2)
      DY=YH(I)-YH(I2)
      D1(N0)=SQRT(DX**2+DY**2)
      CU(N0)=DX/D1(N0)
      SU(N0)=DY/D1(N0)
      S1(N0)=1.0
      C1(N0)=0.0
   10 CONTINUE
      NROW=NS1-1
      JN=-1-NROW
      DO 500 JQ=1,NS1
      KQ=2
      IF(JQ.EQ.1) KQ=1
      IF(JQ.EQ.NS1) KQ=3
      Q1=D1(JQ)/2.
      DO 22 IP=1,NS1
      LQ=0
      IF(IP.EQ.JQ) LQ=1
      CON=D1(IP)/4./PI*U
      SUM1=U0
      SUM2=U0
      SUM3=U0
      AA=CU(IP)*CU(JQ)+SU(IP)*SU(JQ)
C
C H INTEGRATION -- SUBTRACT OUT SINGULARITY IF
JQ=IP
C AND SAME SEGMENT (N11=N21): DESIGNATED LQ=1
C
      DO 100 I=1,NT
      H=Q1*XT(I)
      IF(LQ.NE.1) GO TO 40
      RP=SQRT(H**2+A*A)
      GO TO 50
   40 XP=XS1(JQ)+H*CU(JQ)*S1(JQ)
      YP=YS1(JQ)+H*SU(JQ)*S1(JQ)

RP=SQRT((XS1(IP)-XP)**2+(YS1(IP)-YP)**2+(ZS1(JQ)-ZS
1(IP))**2)
   50 PSI=CEXP(CMPLX(0.,-RP))
c    IF(LQ.NE.1) GO TO 60
c    PSI=PSI-(1.,0.)
   60 PSI=PSI/RP
      SUM1=SUM1+PSI*AA*AT(I)/4.
      SUM2=SUM2+PSI*AA*AT(I)/2./D1(JQ)*H
      SUM3=SUM3+PSI*AT(I)/D1(IP)/D1(JQ)
  100 CONTINUE
      X1=0.
      X2=0.
      X3=0.
c    IF(LQ.NE.1) GO TO 200
c    DQ=D1(JQ)/2.
c    SDQ=SQRT(DQ**2+A**2)
c    X10=ALOG(SDQ+DQ)-ALOG(SDQ-DQ)
c    X1=X10*AA/4.
```

```
c    X3=X10/D1(IP)/D1(JQ)
c 200 CONTINUE
      SUM1=(SUM1*Q1+X1)*CON
      SUM2=(SUM2*Q1+X2)*CON
      SUM3=(SUM3*Q1+X3)*CON
      U5=SUM1-SUM2
      U6=SUM1+SUM2
      U7=-SUM3
      K1=IP+JN
      K2=K1+1
      K3=K1+NROW
      K4=K2+NROW
      GO TO (18,20,19),KQ
   18 CONTINUE
      IF(IP.EQ.1) GO TO 21
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.NS1) GO TO 22
   21 Z(K4)=U6+U7
      GO TO 22
   19 CONTINUE
      IF(IP.EQ.1) GO TO 23
      Z(K1)=Z(K1)+U5+U7
      IF(IP.EQ.NS1) GO TO 22
   23 Z(K2)=Z(K2)+U5-U7
      GO TO 22
   20 CONTINUE
      IF(IP.EQ.1) GO TO 24
      Z(K1)=Z(K1)+U5+U7
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.NS1) GO TO 22
   24 Z(K2)=Z(K2)+U5-U7
      Z(K4)=U6+U7
   22 CONTINUE
      JN=JN+NROW
  500 CONTINUE
      IF(NWIRES.EQ.1) GO TO 297
      NSPTS=0
      DO 291 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      DO 291 I=1,NROW
C
C USE THE SIMPLIFIED METHOD OF HANDLING
MULTIPLE WIRES
C SET COLS TO ZERO FOR STRIPS
C
      IN=(NSPTS-2)*NROW
      Z(IN+I)=U0
      Z(IN+I+NROW)=U0
C
C SET ROWS TO ZERO FOR STRIPS
C
      IN=NSPTS-2+(I-1)*NROW
      Z(IN+1)=U0
      Z(IN+2)=U0
  291 CONTINUE
C
C SET DIAGONALS TO 1 FOR STRIPS
C
      NSPTS=0
      DO 296 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      I0=NSPTS-2
      I1=I0*NROW+NSPTS-2
      Z(I1+1)=(1.,0.)
      Z(I1+NROW+2)=(1.,0.)
```

```
296 CONTINUE
297 RETURN
   END
```

LIST OF REFERENCES

1. Schlesinger, Robert, J., *Principles of Electronic Warfare*, Los Altos, CA, Prentice Hall, p. 132, 1961.

2. "AN/MRC-142 Radio Terminal Set," US Marine Corps Technical Manual TM09543A-12, NSN: 5895-01-333-3040, August, 1992.

3. Kildal, Per-Simon, and Skyttemyr, Svein A., "Dipole-Disk Antenna with Beam-Forming Ring," *IEEE Transactions on Antennas and Propagation*, Vol. AP-30, No. 4, p. 529, July 1982.

4. Pizer, R., *Moment Methods in Electromagnetics*, Research Studies Press Ltd., John Wiley and Sons, 1986.

5. Harrington, R.F., and Mautz, J.R., "H-Field, E-Field, and Combined Field Solution For Bodies of Revolution," Technical Report TR-77-2, Syracuse University, 1977.

6. Balanis, C.A., *Antenna Theory, Analysis and Design*, New York, NY, John Wiley & Sons, 1982.

7. Jenn, D.C., Fletcher, J.E., and Patra, A., "Radar Cross Section of Symmetric Parabolic Reflectors with Cavity-Backed Dipole Feeds," *IEEE Transactions on Antennas and Propagation*, Vol. 41, No. 7, July, 1993.

8. Ordonez, M.V., "Method of Moments Analysis of Symmetric Dual Reflector Antennas with Feeds," Master's Thesis, Naval Postgraduate School, 1992.

9. Butler, C.M., and Wilton, D.R., "Analysis of Various Numerical Techniques Applied to Thin Wire Scatterers," *IEEE Trans. Antennas Propagation*, AP-23, p. 534, 1975.

10. Kumar, A., and Hristov, H.D., *Microwave Cavity Antennas*, Artech House, 1989.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center   2
   Cameron Station
   Alexandria, VA 22304-6145

2. Library, Code 52   2
   Naval Postgraduate School
   Monterey, CA 93943-5101

3. Chairman, Code EC   1
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

4. Professor David C. Jenn, Code EC/Jn   1
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

5. Professor Rama Janaswamy, Code EC/Js   1
   Department of Electrical and Computer Engineering
   Naval Postgraduate School
   Monterey, CA 93943-5121

6. Chairman, Code EW   1
   Electronic Warfare Academic Group
   Naval Postgraduate School
   Monterey, CA 93943-5000

7. Nelson A. Armas   1
   Dirección General De Educación
   Base Naval Sur
   Guayaquil, Ecuador

8. Dirección General De Educación   1
   Base Naval Sur
   Guayaquil, Ecuador